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GEOPHYSICS

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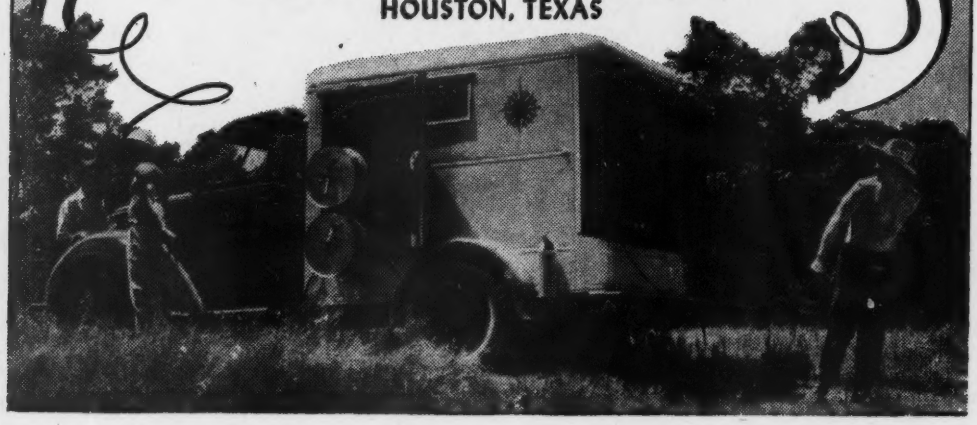

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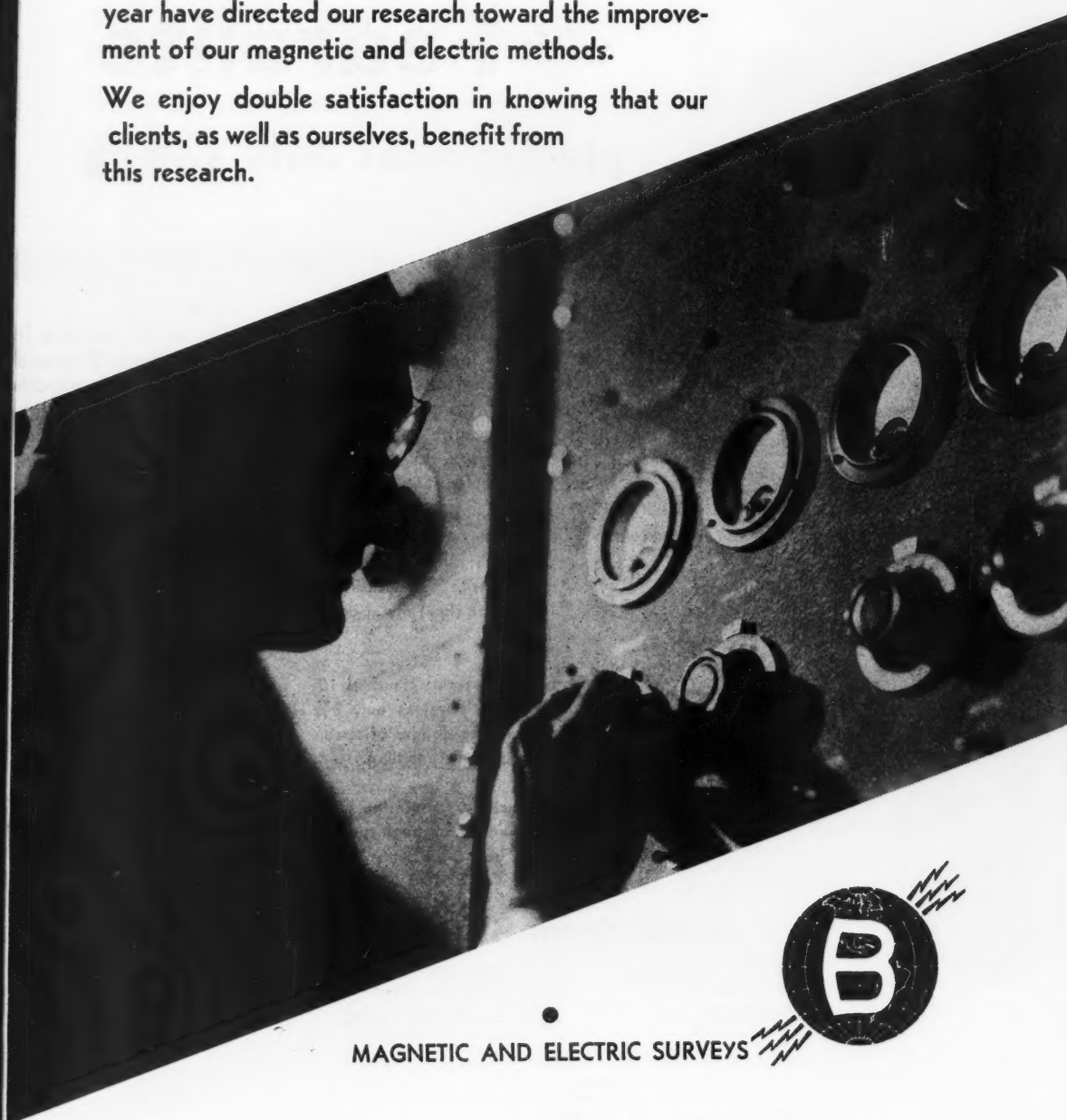

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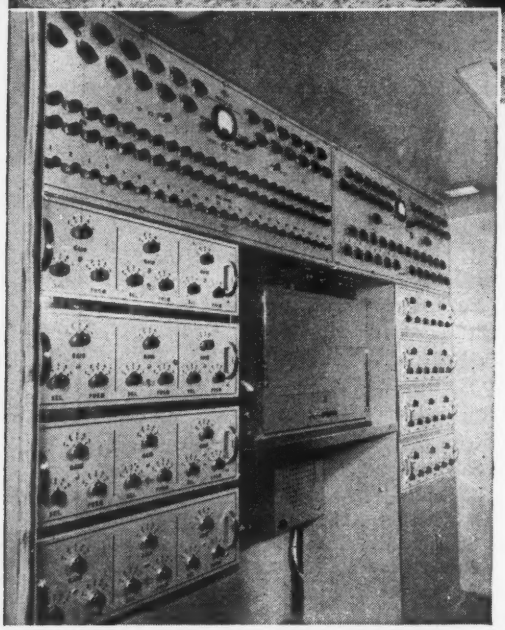

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GEOPHYSICS

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GRAVITY-METER SURVEY OF THE KETTLEMAN HILLS-LOST HILLS TREND, CALIFORNIA*

LEWIS H. BOYD†

ABSTRACT

The gravity anomalies produced by the three Kettleman Hills Domes are maxima. The Lost Hills Anticline produces a gravity minimum. Four maps showing gravity contours, subsurface contours and sections accompany this paper.

Maps from a gravity survey over the Kettleman Hills-Lost Hills Area are compared with previously published subsurface contours and cross sections. These show that the three Kettleman Hills Domes each produce a strong and definite gravity high while the Lost Hills Anticline produces a very clear and closely corresponding gravity low. The paper points out the probable cause of this unusual feature as being a transition within the Reef Ridge Formation from punky, diatomaceous shale at Lost Hills to clays and sands at Kettleman Hills.

A Field crew of the Brown Geophysical Company was employed during 1944 to make a gravity-meter survey along the West side of the San Joaquin Valley, California. This crew completed the work jointly for the Honolulu Oil Corporation and the Barnsdall Oil Company. This paper presents the results obtained by this survey along the Kettleman Hills-Lost Hills trend, which are of particular interest.

It is not the scope of this paper to present the geology of this area, except wherein it has influenced the gravity results obtained. The basic points considered are the gravity-meter results and a discussion of the possible geological reasons for the rather unusual gravity anomalies found in this area.

Accompanying this paper are four maps showing gravity results and idealized subsurface contours. Figure 1 shows the reduced gravity contours drawn from gravity values which have been corrected for

* Read at the Meeting of the Society, Los Angeles, California, November 7, 1945.

† Geophysicist, Brown Geophysical Company, Houston, Texas.

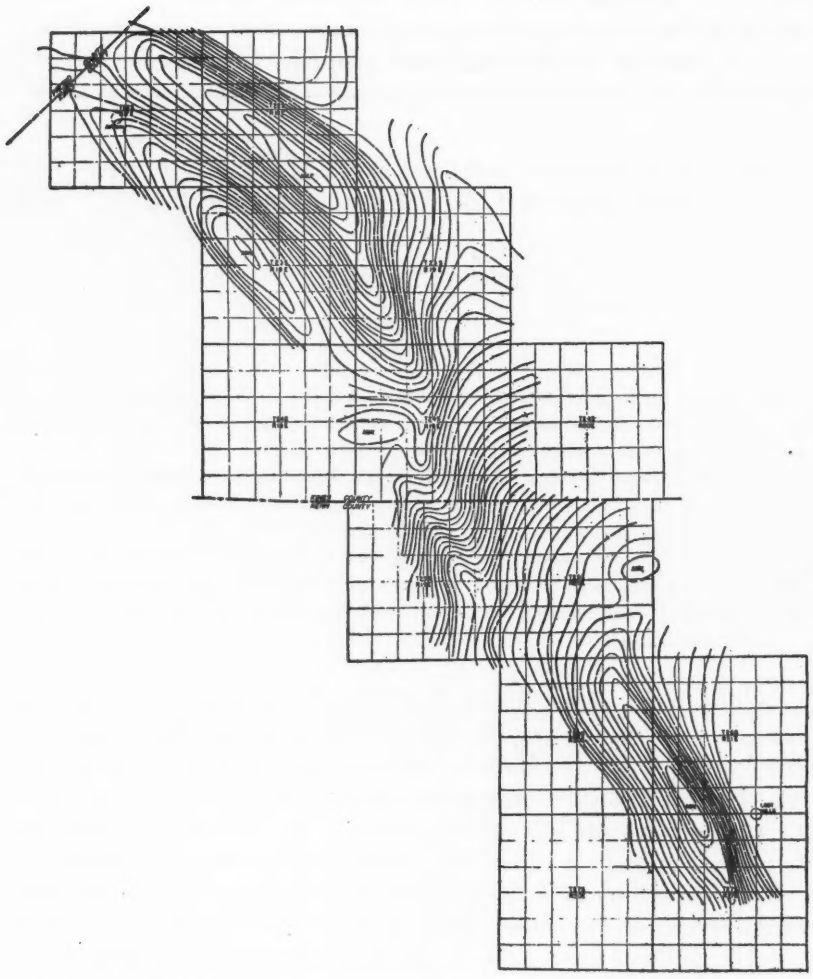

FIG. 1. Gravity survey, Lost Hills-Kettleman Hills Area, California.
Contours of observed gravity; Contour interval 0.5 mg.

elevation changes and geodetic positions only. In the preparation of the map a combined correction for the Free Air Effect and the Bouguer Effect of 0.069 milligals per foot has been used; this correction corresponds to a density of approximately 2.0 for the surface sediments. Latitude corrections have been based on the International Formula for Gravity as used by the U. S. Coast and Geodetic Survey.

Figure 2 shows the residual gravity contours produced by removing the regional gradients mathematically. The method used in the preparation of these maps is one that has been used successfully by the Brown Geophysical Company for several years to aid in the interpretation of the results obtained from making gravity-meter surveys in many parts of the country. The mathematical procedure and derivation of this method are not a function of this paper.

Figure 3 depicts the idealized subsurface contours along this trend, from the sources indicated in the caption.

Figure 4 consists of three gravity profiles taken across Lost Hills Oil Field at intervals of about two miles and an idealized subsurface cross section to illustrate the correlation between gravity and structure on this feature.

A reference to Figure 1 shows that a pronounced gravity maximum closure has been contoured in T. 22 S., R. 18 E. This gravity maximum correlates closely with the structural closure on Kettleman North Dome. All gravity contours on this map are on an interval of 0.50 milligals. To the southeast of this closure there occurs a slight offset in the direction of the contours and the axis. At this point a flattening of the gradient occurs down the nose. A second gravity anomaly of importance is then encountered which forms a steep maximum nosing. The location of this anomaly correlates closely with the location of Kettleman Middle Dome. The axis of this nose turns sharply to the south and the gradient again flattens. A third gravity anomaly occurs here very similar to the one described above. This forms a steep maximum nosing occurring mainly in T. 25 S., R. 19 E. The location of this anomaly correlates very well with the location of Kettleman South Dome. At the termination of this anomaly a zone of flatter gradients is encountered and in T. 26 S., R. 20 E., a very pronounced gravity minimum has been found to extend in a southeasterly direction into T. 27 S., R. 21 E. This gravity minimum correlates extremely well with the location of the Lost Hills Anticline.

Attention is now called to Figure 2, which shows the residual gravity contoured on an interval of 0.50 milligals. It is to be noted on this

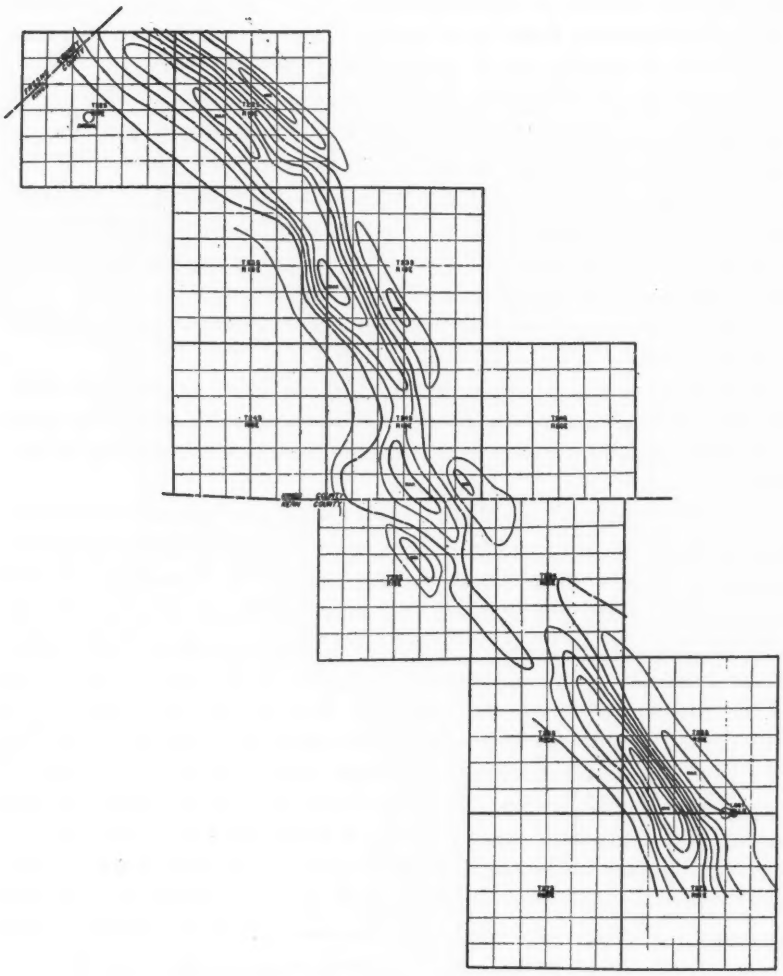

FIG. 2. Residual gravity, Lost Hills-Kettleman Hills Area, California. Contour interval 0.5 mg.

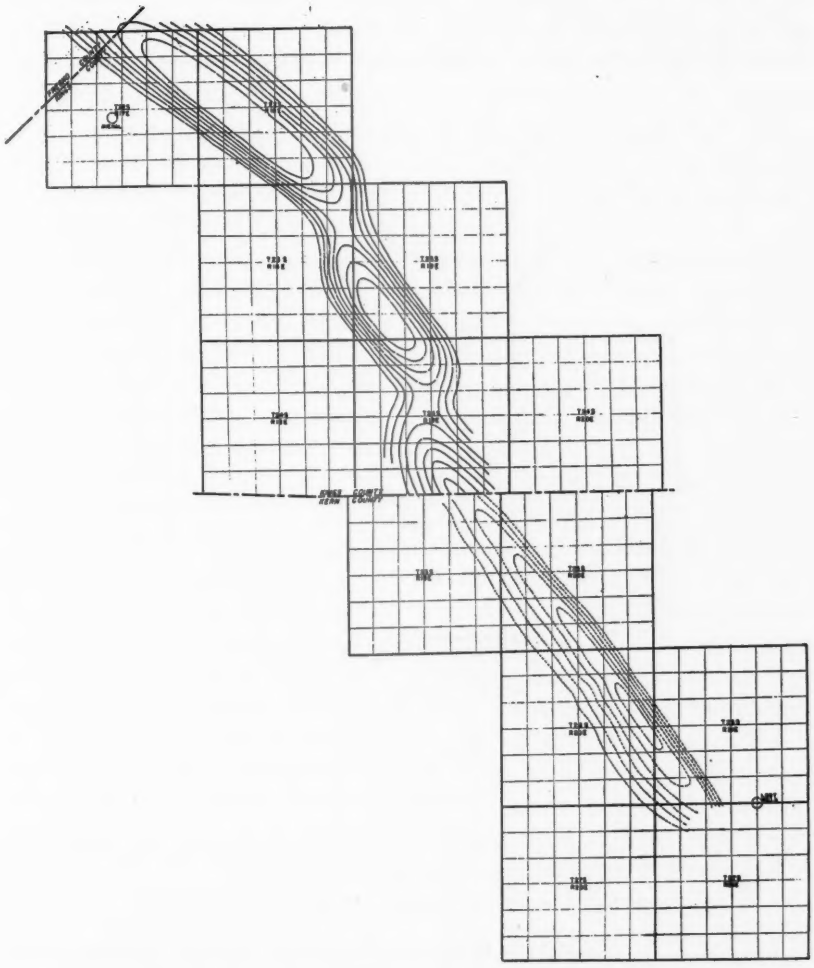

FIG. 3. Subsurface contours for comparison with residual gravity of Fig. 2. Contours in Kettleman Hills Area (North of Kings-Kern County line) after Uren (California Div. of Mines, Bull. 118, Part One, p. 45), Contour interval 500 ft.; in Lost Hills Area, on top of Temblor, after Follansbee (California Div. of Mines, Bull. 118, Part Three, p. 495). Contour Interval 1000 feet.

map that the positions of the residual anomalies follow very closely those described above. In the cases of Kettleman Middle Dome and Kettleman South Dome, the residual anomalies show considerable gravity closure which correlate closely with the structural closure found in these two areas. A comparison between Figures 2 and 3 will

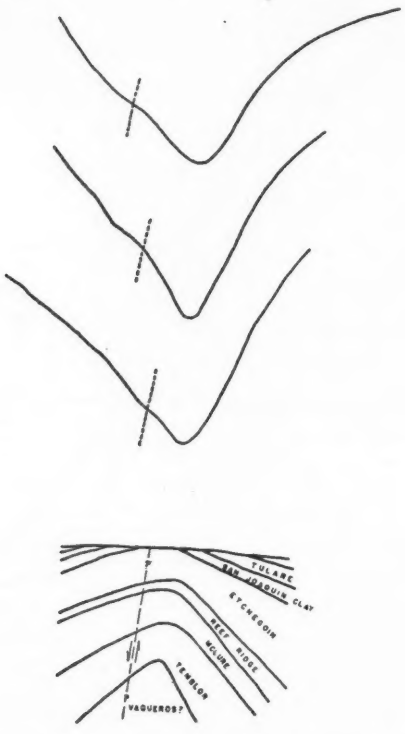

FIG. 4. *Upper:* NE-SW profiles of observed gravity across the Lost Hills Oil Field, at interval of about two miles.
Lower: Cross Section of Lost Hills structure, after Follansbee.

show the close correlation between the gravity results and the structural anomalies present along this trend. Again Figure 2 shows that a minimum gravity anomaly correlates closely with the position of Lost Hills. The zone between this anomaly and Kettleman South Dome shows an irregular gravity pattern.

There must be some geological reason for this rather remarkable phenomena of such a sudden change from gravity maximum representing a structural high at South Dome to a gravity minimum representing a structural high at Lost Hills. An examination of the stratigraphy

at Lost Hills shows a considerable thickness of the Reef Ridge (Miocene) Shales. These shales are described as being punky and diatomaceous. Specific gravities have been run on several dry samples of this shale which show an average of about 0.9. At the northern end of the structure these shales have a thickness of about 900 feet, which increases somewhat to the south. The extremely steep flanks of this anticline cause a considerable thickness of this shale to be present vertically below the surface on either flank. It is probable, then, that this extremely light material, being present over the structure, is sufficient to produce the Lost Hills gravity minimum.

Along this same trend the Reef Ridge as found over Kettleman Hills is composed mainly of harder shales, clays, and sands with a thickness varying from 600 to 800 feet. This is underlain by from 1200 to 2000 feet of McClure Shale. Both of these formations are relatively hard and have a much higher specific gravity than the diatomaceous shale found at Lost Hills. At Lost Hills the Reef Ridge is underlain by the McClure Brown Shale, which varies from 1200 to 1400 feet in thickness. This has approximately the same density here as at Kettleman. The outstanding density variation in this area then is the lightness of the Reef Ridge at Lost Hills. These gravity anomalies then show a probable transition within the Reef Ridge from Lost Hills to Kettleman North Dome. They also bring out the probability that the diatomaceous material deposited at Lost Hills in the Reef Ridge is not present farther north on the trend at Kettleman South Dome.

Figure 4 illustrates the correlation between the gravity profiles across Lost Hills and an ideal cross section as shown by Follansbee.[1] This section shows that the steep side of the anticline is on the northeast flank. The gravity anomaly also shows this to have the steeper gradient. The axis of the gravity anomaly correlates almost perfectly with the axis of the subsurface structure. A second interesting feature is the slight change in gradient of the gravity profile to be noted on the southwest flank of the anomaly. The point of curvature of this gradient change has been marked on the profiles with a dotted line. It is quite possible that this break has been produced by the possible fault shown on Follansbee's section.

The author wishes to take this opportunity to thank Mr. Elmo W. Adams of the Honolulu Oil Corporation and the Late Dr. E. Wayne Galliher of the Barnsdall Oil Company for their permission to publish these results.

[1] G. S. Follansbee, Jr. *Lost Hills Oil Field,* state of California, Division of Mines, Bulletin 118, Part Three, p. 495.

SEISMOGRAPH EVIDENCE ON DEPTH OF SALT COLUMN, MOSS BLUFF DOME, TEXAS*

H. WAYNE HOYLMAN†

ABSTRACT

Clear reflections at times of approximately 2.3 and 4.4 seconds were obtained consistently on a series of records shot directly over the shallow cap rock of the Moss Bluff dome. The earlier reflection can be interpreted as from the base of the salt column, at a depth of around 16,000 feet, or from a discontinuity within the salt column. The later reflection can be interpreted as from the base of the salt column at around 36,000 feet, from the basement complex at around 26,000 feet, or as a multiple of the reflection from the base of the salt column at around 16,000 feet. Reasons are given for preferring the multiple reflection interpretation.

INTRODUCTION

The purpose of this paper is to discuss two plausible interpretations of some unusual reflections which have been recorded by seismograph shooting directly over the top of the Moss Bluff salt dome in the Texas Gulf Coast. The important detail set forth is a computed depth to the base of the salt which is surprisingly shallow.

Moss Bluff dome, in the southeastern Texas Gulf Coast area, is located on the south line of Liberty County and extends south into Chambers County. (See Fig. 1) It is reported to have been discovered by the refraction seismograph in 1926. It is a shallow elliptical dome with the top of the cap rock at about 650 feet. The top of the salt is at an average depth of about 1,150 feet, which gives an average thickness of 500 feet for the cap rock. On the east side of the dome, the Oligocene is found just below 5000 feet. The flanks of this dome are practically vertical.

SEISMIC DATA

A—Description of Records

In connection with a recent seismograph survey in Liberty and Chambers Counties, a two way continuous profile was run across the central part of Moss Bluff (see Shot Points 3 to 6, Fig. 1). On this north-south traverse, a number of records were obtained from shots directly over the top of the dome.

* Read at the meetings of the Society, Tulsa, Houston, Dallas, and Los Angeles, 1945.

† Gulf Research & Development Company, Pittsburgh, Pa.

Fig. 2 shows sample records obtained from the last two shot points (Nos. 5 and 6) at the south edge of the dome. Although only four records are shown, records similar to those for Shot Point 5 were obtained from Shot Points 3 and 4. To obtain this type of record, a ten-pound charge was detonated at an average depth of fifty feet. Un-

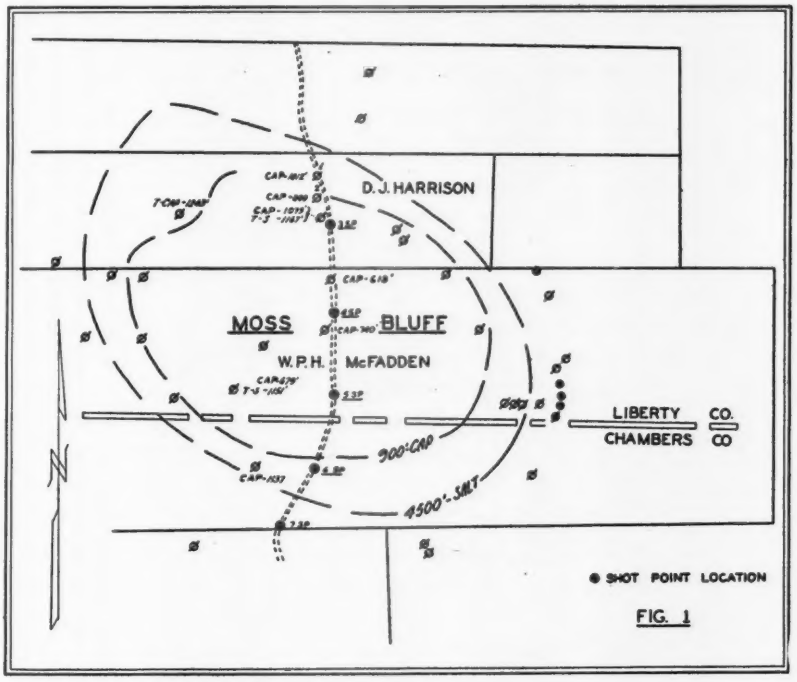

FIG. 1. Sketch map, Moss Bluff Dome, with approximate shape of cap rock and salt shown by 900 ft. and 4,500 ft. contours, respectively. Records from two-way speeds from shot points 3 to 6 gave the reflections which are the subject of this report.

fortunately, no effort was made to get any transverse spreads along the profile.

As can be noted from Fig. 2, there is no or very little evidence of reflections appearing in the background of random noise until about two and one-half seconds of elapsed time. At this level, there is a strong reflection after which there is reoccurrence of the random noise until approximately four and one-half seconds have passed, at which time a fairly strong reflection is again recorded.

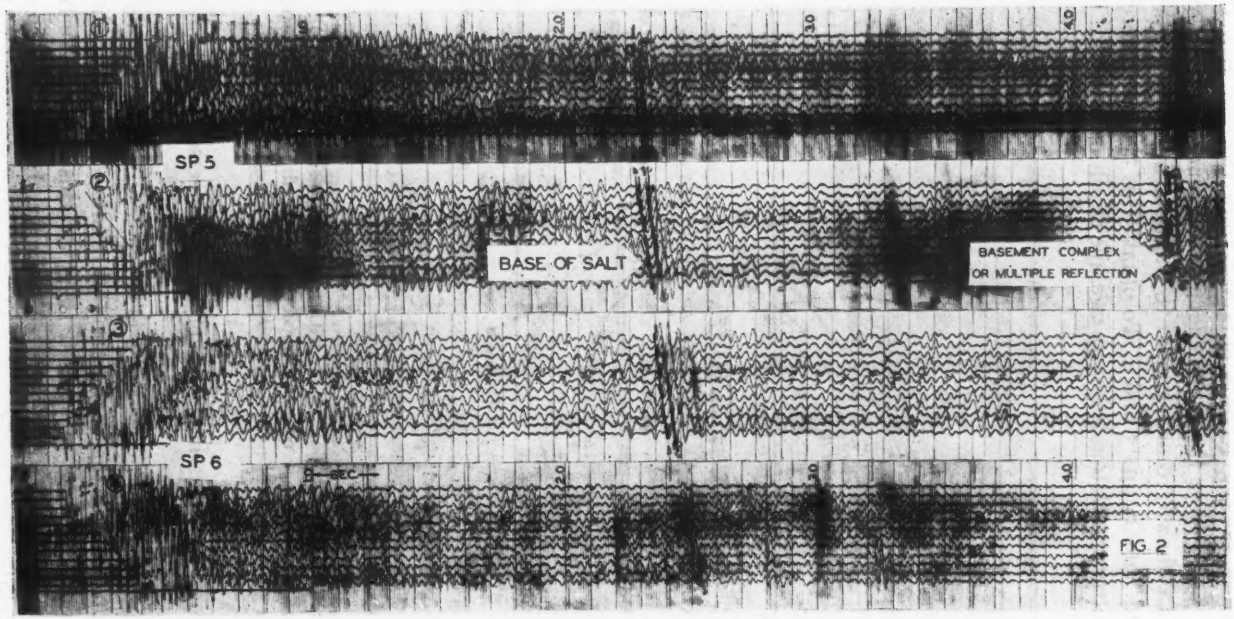

FIG. 2. Four reflection records from shot points 5 and 6 of Fig. 1. Note that the upper three records have strong reflections at 2.3 and 4.4 Sec., while these are absent from the bottom record, shot south from shot point 6. First reflections in upper records are believed to be from base of the salt column at a depth of approximately 16,000′; second reflections are believed to be multiples of the first but may be from the basement rocks. Absence of reflections from bottom record is because reflection path would be outside of dome with sediments dipping away from the dome.

B—Vertical Speed of Formations

In connection with determining the depth to the reflecting horizons implied by the reflections, vertical speeds were used as follows:

1.	Sediments overlying cap rock	6,000 ft./sec. (measured)
2.	Cap rock	19,000 ft./sec. (measured)
3.	Salt	14,800 ft./sec. (measured)
4.	Sediments below base of salt	10,000 ft./sec. (assumed, speed, constant with depth)

There is actually very little evidence from which to assume the speed below the base of the salt, but that available indicates 10,000 ft./sec. is not unreasonable.

INTERPRETATION

A—Shallow Reflection

Inasmuch as the shallower reflection is recorded only on the records from shots directly over the dome, the most logical assumption is that it is being reflected from the base of the salt. This necessitates the assumption that the salt mass within the dome is homogeneous.

On this basis, and using the speeds given above, the depth to the base of the salt is found to be approximately 16,000 feet. This is unquestionably a surprisingly shallow depth. In other parts of the Gulf Coast, geophysical data (principally calculations to explain gravity anomalies) have indicated the depth of salt to be of the order of 25,000 feet.

B—Deep Reflection

As for the deep reflection, three plausible sources may be suggested as follows:

1. Base of the salt
2. Top of the basement complex
3. Multiple reflection

Assuming the first source, the calculated depth to the base of the salt is 36,000 feet. This depth is much greater than the usual estimates based on geology and geophysics.[1]

This interpretation requires a discontinuity of some kind within the dome to account for the shallower reflection. The writer knows of

[1] D. C. Barton, C. H. Ritz, and Maude Hickey. *Gulf Coast Geosyncline*, Bull. A.A.P.G. 17, No. 12 (Dec. 1933), p. 1450.

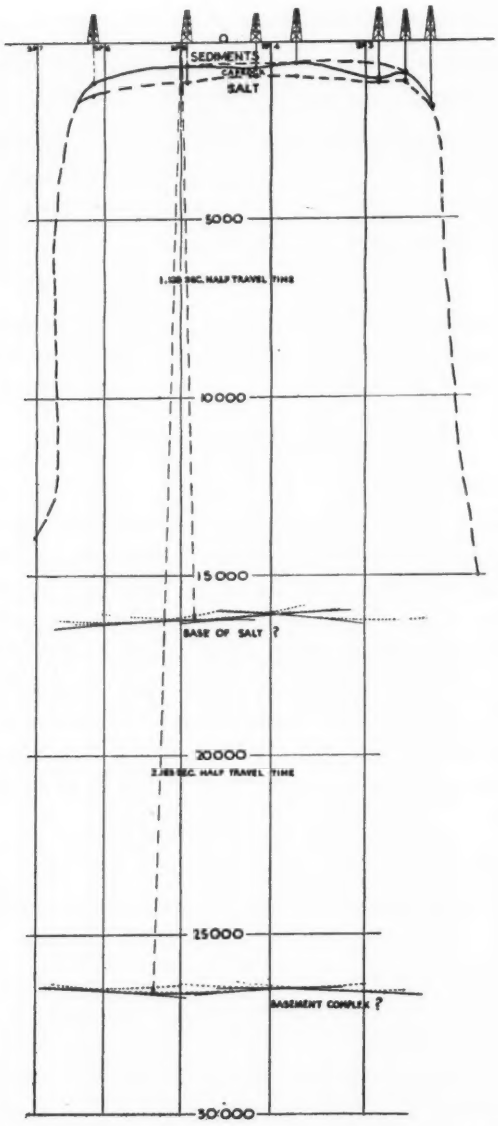

FIG. 3. Cross Section, Moss Bluff Dome, showing tests drilled into dome and possible reflection horizons.

no explanation, in the geology of salt domes, of a continuous, horizontal boundary extending across the middle of the salt column of a

dome which would be required to account for the consistent intermediate reflection recorded from a series of shot points across the top of the dome.

If the basement complex is the reflecting horizon, the calculated depth, using the speeds given above, is approximately 26,000 feet. This would require that the shallower reflection arise from the base of the salt. Fig. 3 has been made to show the base of the salt at 16,000 feet and the basement at 26,000 feet, as calculated for this interpretation.

C—*Multiple Reflection*

If it is assumed that the later reflection is a multiple, it becomes of first order of importance to determine where the interface near the surface of the ground is located. The most logical place to suspect is where the largest discontinuity in the velocity exists. This would be at the contact between the top of the cap rock and the overlying sediments. The position of this contact must be determined from well calls.

In Fig. 3, it can be seen that near Shot Point 5 a well has been drilled through the cap rock and into the salt. Here the cap is 475 feet thick with 680 feet of overlying sediments. Using these thicknesses, and the cap rock and salt speeds given above, the time calculated for a path from shot point to base of salt at 16,000 feet, to top of cap, back down to base of salt, and up to the detector agrees to within 0.003 sec. of the observed reflection time.

If the deep reflection on the records from Shot Point 5 is correlated with the other records, it is found that the positions of the interface calculated on the assumption of multiple reflections coincides with the contact between the cap rock and the overlying sediments as given by drilling at all locations except Shot Point 3. At this point, as shown in Fig. 3, the cap rock is abnormally thin as given by the well calls, and the calculated interface is approximately 375 feet above the top of the abnormally thin cap rock. If an average thickness is assumed in the vicinity of Shot Point 3, as is shown by the dashed line in Fig. 3, the calculated interface falls within 50 feet of this average.

Because of the apparent check of the position of the contact of the cap rock within 0.003 sec. at three shot points, it is believed that the deep events are more logically explained as multiple reflections rather than as arising from the basement complex.

Although this deduction is drawn, the point should not be over-

looked that an occasional record, as shown in Fig. 2, has a suggestion of a deep but weak reflection which, offhand, mitigates against the multiple reflection hypothesis. However, from a study of many records shot under the same conditions as these over Moss Bluff, it has been learned that, apparently, the salt-sediment interface is not always a good reflecting surface; at least, the amplitude and character of the reflections are quite variable. It would seem, therefore, that between the salt and the sediments there may exist in many domes either an intermediate transition zone of lithological gradation or a ragged interface caused by infolding of salt and sediments. However, at Moss Bluff, this general condition must not exist, as a sharp interface must be present to give the deep reflection.

Another point lending credence to the multiple reflection hypothesis is the difference in the two records obtained in shooting in opposite directions from Shot Point 6. This shot point is on the very edge of the cap rock. The record shot away from the center of the dome has no reflections at either level, while, in the other direction, both levels are clearly shown. This is exactly what is to be expected in shooting near the edge of the dome.

CONCLUSION

Because of the meager amount of data that are available, no definite conclusions can be drawn from the foregoing discussion. It is suspected, however, that the base of the salt at Moss Bluff is approximately 16,000 feet below the surface and that the deep reflections are multiples.

ACKNOWLEDGMENT

The seismic work on which the above conclusions are drawn was carried out at the suggestion of various members of the geophysical staff of the Gulf Research & Development Company. The writer wishes to acknowledge his indebtedness to Mr. William C. Lamb for valuable suggestions and to Dr. E. A. Eckhardt for permission to publish this paper. The writer has served merely to compile the results.

THE DEVELOPMENT AND APPLICATIONS OF AIRBORNE MAGNETOMETERS IN THE U.S.S.R.

A. A. LOGACHEV
H. E. HAWKES,* *Translator*

TRANSLATOR'S NOTE: These three papers by A. A. Logachev describe the pioneer work by the Russians in magnetic exploration with airborne equipment. Partly because of the language and partly because of the obscurity of the journals in which it was published, information on this work has not been widely circulated among American geophysicists. It is hoped that these translations will be of historical if not of practical interest to the profession.

Miss Taisia Stadnichenko of the Geological Survey has checked the translations for errors and misinterpretations.

EDITOR'S NOTE: The translations of these three papers are published at this time because of the current interest in the subject and because this early work apparently is very little known to the American geophysical profession (although English abstracts of the papers were published currently in abstract journals). The figures have been redrawn by tracing enlargements of the originals.

EXPERIMENTAL MAGNETIC SURVEY BY AIRPLANE†

The first experimental magnetic survey by airplane was conducted over the Staraya Russa magnetic anomaly between the 19th and 21st of July, 1936. The survey was organized by the Central Geological and Prospecting Institute (TsNIGRI), and carried out by A. A. Logachev, designer of the apparatus, together with A. T. Maiboroda.

The apparatus consisted of an induction coil with a bi-plate collector and brushes on a rotating commutator. It was designed for the measurement of the vertical component of the earth's field.

The rotating coil is driven by an electric motor. The inductor and motor are suspended on gimbals in such a manner that the axis of rotation is always horizontal. The commutator and brushes are adjusted so that commutation of the current occurs at the moment of maximum e.m.f. resulting from the vertical component, and minimum e.m.f. from the horizontal component. A sensitive direct-current galvanometer is shunted into the circuit. When the coil is rotating at high speeds, the galvanometer records only that part of the current which

* Geologist, U. S. Geological Survey.
Published with permission of the Director.
† Razvedka Nedr, No. 17, pp. 40–41, 1936.

is proportional to the vertical field, as the net current resulting from the horizontal field will be equal to zero.

Measurements are based on the principle of full compensation of the vertical magnetic field. The compensation is made in the following manner. The vertical field of the earth is opposed by fixed magnets whose fields are equivalent to the minimum value of the vertical component which may be expected in the course of the projected survey. The residual field is then compensated by the magnetic field from a current flowing in a fixed coil wound around the body of the instrument. Current in the fixed coil is supplied by constant voltage batteries. A rheostat regulating the current in the fixed coil is connected

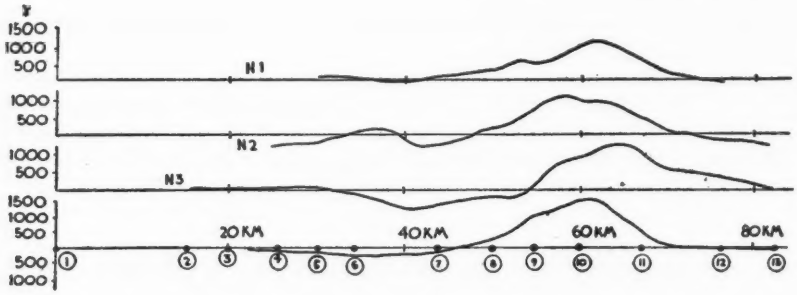

FIG. 1. Magnetic Curves, Novgorod to Valdai. Curve 1, Altitude 1000 meters; Curves 2 and 3, Altitude 300 meters; Curve 4, traverse on ground with Schmidt balances. Place names: 1. Novgorod, 2. Kholynya, 3. Bolshoe Luchino, 4. Zavod Proletarii, 5. Dorozhno, 6. Krasnye Stanki, 7. Kunkino, 8. Zaitsevo, 9. Lipgora, 10 Viny, 11. Moshka, 12. Dolgii Most, 13. Kresttsy.

to a pen which records the resistance of the circuit on a moving tape. In practice, the recorder was actuated by a potentiometer rather than directly by the rheostat. The null-point of the galvanometer indicates complete compensation. This method of measuring the magnetic field is free from errors arising from variations in speed of rotation of the induction coil, as any variations in speed will affect only the accuracy of the instrument.

For the test survey we were offered a two-seated, open-cockpit airplane. Because of weight limitations we were forced to eliminate the recorder, and had to forego a continuous record in favor of visual observations taken every other minute.

The flight was laid out over the northern part of the Staraya Russa magnetic anomaly along a line about 60 km. in length passing from

Novgorod to Valdai. According to data gathered by the Bureau of Geomagnetic Surveys, the magnetic intensity along this line ranges from −230 gammas to 1430 gammas.

Results of the survey are presented in the form of three curves (Fig. 1). Curve No. 1 represents a survey at an altitude of 1000 meters. Owing to low clouds ground control was lost at the end of the flight.

Curves No. 2 and 3 represent traverses from Novgorod to Valdai and back at an altitude of 300 meters. For comparison, curve No. 4 shows observations on the ground with Schmidt balances, taken from data published by the Bureau of Geomagnetic Surveys.

The anomaly is shown quite distinctly on all three curves. The notable displacement of the maximum may be the effect of errors in orientation; the divergence in values of the anomaly may be ascribed to instrumental error.

We may conclude as a result of our survey that magnetic anomalies which are greater than 1000 gammas in total intensity may be measured with the air-borne instrument of our construction.

July 29, 1936

MAGNETIC SURVEY BY AIRPLANE IN THE ZAPADNAYA OBLAST*

After the experimental survey by airplane over the weak Staraya Russa magnetic anomaly, the Central Geological and Prospecting Institute (TsNIGRI) organized an experimental aerial survey over the strong anomalies of the order of 30,000 gammas within the limits of the Zapadnaya oblast (Western district). The author was assisted by A. A. Strona, senior engineer of the Institute who laid out the flights, and by I, V. Ryazantsev, airplane mechanic.

The instrument was redesigned and completely rebuilt, with a resulting reduction in mechanical friction and air resistance of the rotating coil. The total weight was 30 kg., as compared with 72 kg. for the previous equipment. It was installed in the airplane at the Smolensk airdrome, which also served as the operating base.

The construction of the new equipment delayed our departure. As a result, the field work was done in late September and early October under extremely unfavorable weather conditions—low clouds, almost constant rain or snow, and relatively strong winds. The airplane was an open-cockpit type, and the cold and precipitation seriously interfered with the work.

* Razvedka Nedr, vol. 7, No. 51, pp. 34–37, 1937.

Measurements were made over the Baryatinsk and Rognedinsk anomalies, and along a line from Smolensk to Baryatinsk station(about 150 km.). All results are presented in the form of graphs.

Fig. 1 shows vertical intensity curves on two parallel traverses along the Smolensk-Sukhinichi railway, between the Dnepr river on the west and the Warsaw highway on the east. Along this line the magnetic field is known only from scattered observations of absolute intensity. During the flight out from Smolensk (lower curve) we have an apparent normal field as far as Spas-Deminsk; between the latter

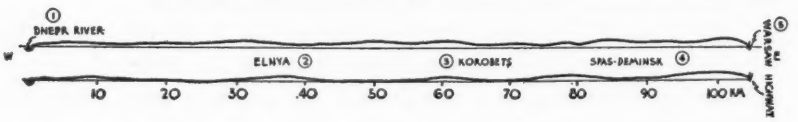

FIG. 1. Two vertical intensity curves recorded by airplane along the Smolensk-Sukhinichi railway between the Dnepr river and the Warsaw highway.

and the Warsaw highway, an increment in the order of 2000 to 2500 gammas was recorded. The results of the survey beyond the Warsaw highway are shown in Figs. 2 and 3. During the return flight (upper curve) the anomaly in the vicinity of Spas-Deminsk is again recorded, indicating that between the Warsaw highway and Spas-Deminsk the vertical intensity is actually somewhat greater than normal. Further on the route to Smolensk beyond Spas-Deminsk, the vertical intensity again increases by about 1500 gammas and then remains fairly constant as far as the Dnepr. This variation is probably not caused by an actual change in the earth's field, but is more probably due to one of the following two causes: (1) a change in readings resulting from instrumental drift after four hours of steady operation (possibly the effect of a current leak due to dampness, or of a shift in position of the collector brushes); (2) a change in the magnetic field of the motor of the airplane, produced by greater speed on the return trip. An error in the instrument itself seems unlikely, as it was tested repeatedly in the course of the survey and showed no observed change in its behavior. A change in the magnetic field of the motor, however, could very well have accounted for the discrepancies, as the motor was not shielded and some observed changes in instrument readings were correlated with changes in r.p.m. This effect was particularly noticeable beyond the Dnepr as we were returning to Smolensk, where the readings again became normal (this part of the curve is not shown in Fig. 1).

Fig. 2 shows the location of flight lines and magnetic contours drawn from surface observations over the Baryatinsk anomaly east

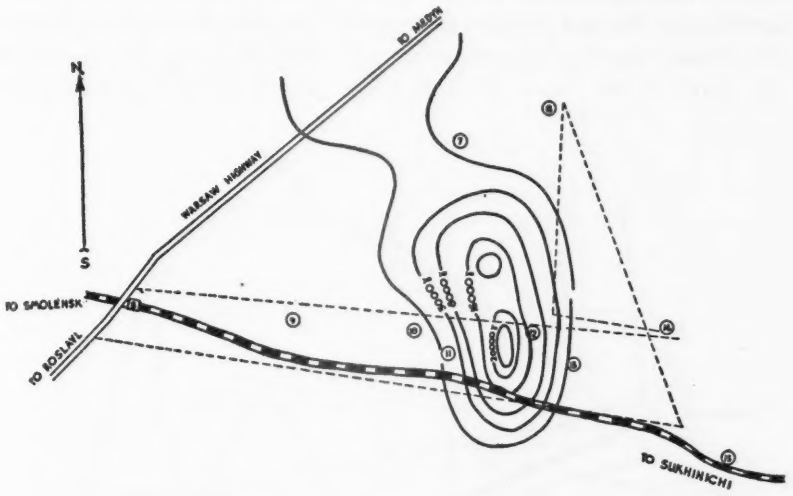

FIG. 2. Vertical intensity contours on the ground over the Baryatinsk magnetic anomaly. Broken lines indicate aerial traverses. See Fig. 3 for scale. Place names: 6. Kholmi, 7. Zimnitsi, 8. Chiplyaevo station, 9. Zanoznaya, 10. Vysokaya Gora, 11. Shemelinki, 12. Shershnevo, 13. Krasnyi Kholm, 14. Butyrki, 15. Kobylye.

of the Warsaw highway. Fig. 3 shows vertical intensity curves along the flight lines. The pilot was instructed to cross the strongest part of the anomaly at different elevations, but low clouds (200 to 300 meters) and strong winds interfered with the plan. At the end of the first traverse the pilot brought the airplane to a point considerably south of where we had planned to come out, indicating that we had crossed only the southern part of the anomaly. After that the location of flight lines was determined in part by occasional glimpses of recognizable landmarks, in part by noting the elapsed time between turns, but chiefly by the anomaly as it was being recorded. Then, by using the map of the magnetic anomaly in conjunction with the instrument readings, we were able to determine our course fairly accurately. Thus in this flight we reversed our problem, and instead of determining magnetic intensity over known terrane we determined our location by instrument readings over known magnetic features. The anomaly has been outlined quite satisfactorily, as may be seen in the illustration.

The Rognedinsk anomaly is located about 130 km. from Smolensk along the Roslavl-Sukhinichi railway between the Oster and Desna rivers. The railway line and the rivers at each end served as excellent landmarks. We had planned to cross the anomaly six times at different elevations, starting at 1000 meters and working down. We arrived in the midst of low clouds and rain which prevented us from taking ob-

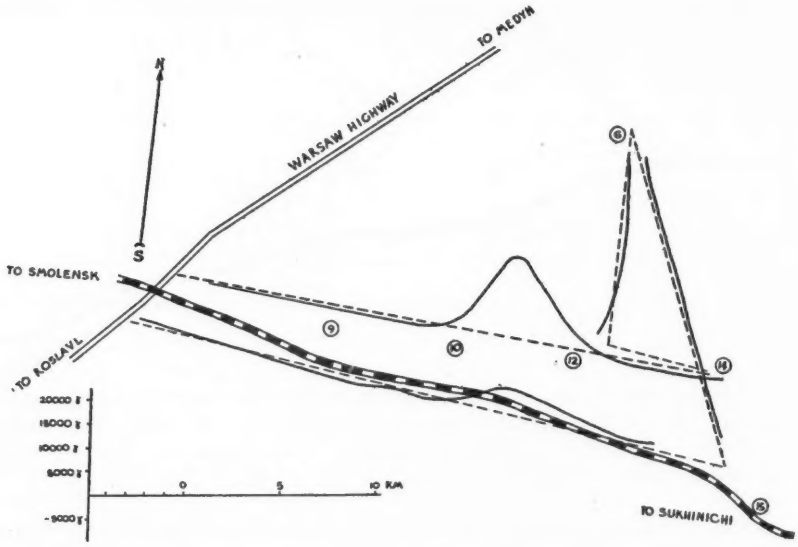

FIG. 3. Vertical intensity curves from the aerial survey over the Baryatinsk anomaly. Place names: 9. Zanoznaya, 10. Vysokaya Gora, 12. Shershnevo, 14. Butyrki-15. Kobylye.

servations at this elevation. The clouds were continually shifting and the pilot, who was anxious to gain altitude, did not hold the plane at a constant level during any one traverse. Thus, all six curves were recorded at a variable elevation ranging from 200 to 300 meters. Curve No. 1 (reading from bottom to top in Fig. 4) was recorded at an elevation of about 300 meters. No. 2 was below 200 meters; the compensating field in the fixed coil was not sufficient to record the maximum anomaly, and the curve was interrupted while the instrument was adjusted for greater compensation. No. 3 was recorded at an elevation somewhat greater than 200 meters. No. 4 started at an elevation above 300 meters, but over the anomaly itself the airplane was

descending because of the appearance of low clouds. No. 5 was at 300 meters and No. 6 at 200 meters.

The altimeter was read by the pilot who communicated the information to the operator. The accuracy of these data is not great. In any further work it will be necessary to provide the operator with

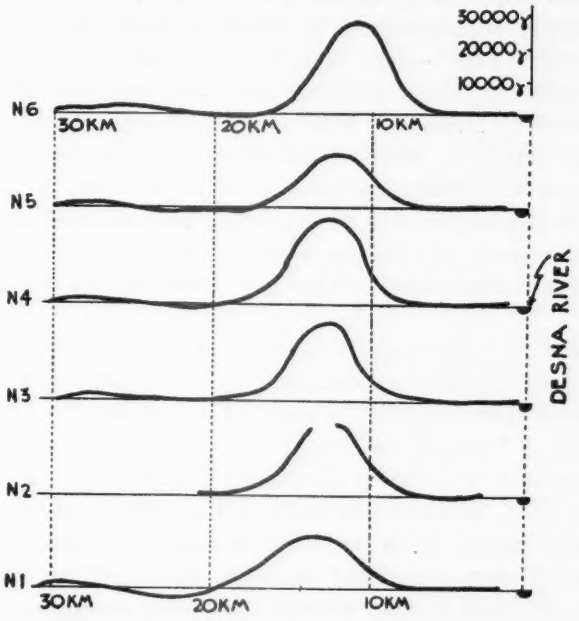

FIG. 4. Vertical intensity curves observed from the air along the Roslavl-Sukhinichi railway between the Oster and Desna rivers (Rognedinsk anomaly). Elevations of flights: Curve 1, 300 meters, Curve 2, below 200 m.; Curve 3, above 200 m.; Curve 4, start at 300 m.; lower over anomaly; Curve 5, 300 m.; Curve 6, 200 m.

an altimeter. In this connection, attention should be drawn to the fact that at a distance of about 25 km from Desna all the curves show small increments in vertical intensity which are greater at lower elevations. Evidently we have here a weak anomaly.

Discrepancies in maximum values of vertical intensity may be explained by the variable elevation of the flights. If the elevation were known more accurately, the maximum values could be used in calculating the depth to the center of the magnetic body. As may be seen in the diagram, discrepancies in the horizontal position of the curves

are negligible, as a result of the accurate orientation made possible by the railway line and the rivers. The accuracy with which the anomalies were located may be seen in the diagram.

Disregarding the unexplained changes in vertical intensity observed on the traverses between Smolensk and the Warsaw highway, we find that the accuracy of our survey in the Zapadnaya oblast was approximately 1000 gammas. It should be borne in mind that the work was carried out under extremely unfavorable weather conditions.

The results of this project once more prove the feasibility of magnetic surveys by airplane. The accuracy of measurements will depend to a large extent on weather conditions. Our results indicate that anomalies greater than 2000 gammas can be measured in any weather in which it is possible to fly. In calm and clear weather anomalies of quite low intensity can be measured, as was found in our flights over the Staraya Russa anomaly when even less sensitive equipment was used.

The use of aerial magnetic surveys in geological exploration will permit a wider application of magnetic methods not only in the search for magnetic orebodies, but in the study of regional geology as well. Surveys at different elevations provide new data which may prove to be extremely valuable in computing the depth to the center of a magnetic body. It should be realized that aerial surveys would be particularly important in the study of regional anomalies, as anomalies arising from superficial magnetic masses of no regional significance will tend to fade out with increased elevation. Finally, an obvious advantage of aerial magnetic surveys is the speed with which large and inaccessible areas may be investigated—a speed unprecedented in any previous geophysical work.

AN EXPERIMENTAL APPLICATION OF THE AEROMAGNETIC SURVEY TO THE DETERMINATION OF DEPTHS IN MAGNETIC MASSES*

In 1937 the Central Geological and Prospecting Institute (TsNIGRI) conducted an experimental magnetic survey of the Kursk magnetic anomaly near the town of Staryi Oskol.[1]

* Materialy, Tsentral'nogo Nauchno-Issledovatel'skogo Geologo-Razvedochnogo Instituta, Geofizika, Sbornik 8 (Also English title: Materials of the Central Geological and Prospecting Institute, Geophysics, Fascicle 8), pp. 35–38, 1940.

[1] Raboty po magnitnoi s'emke s samolet, kratki izlozhennye avtorom v zhurnale: (Work on magnetic surveying by airplane, briefly summarized by the author in the journal:) Razvedka Nedr No. 17, 1936 and No. 5, 1937.

The work was done by the author together with A. I. Garnov, engineer of the Institute, and A. I. Dyukov, engineer of the Geological Exploration Trust for the Kursk magnetic anomaly.

One of the unsolved problems was to determine whether the depths of the upper and lower limits of the Kursk ferrous quartzites could be computed from aeromagnetic data. The depth of the upper limit of the body was known sufficiently well from underground development, but no trustworthy data existed concerning the lower limits.

Four traverse lines were laid out approximately at right angles to the strike of the quartzites. A total of 22 traverses were run at elevations from 500 to 1600 meters. Five of these were rejected for various reasons (lack of experience on the part of the observer appears to be the ultimate cause in every case); the remainder of the curves were used in solving the problem at hand.

For the problem which we are considering in the present article, we make use of curves recorded between Staryi Oskol and Saltykovo over the most intense part of the anomaly.[2] Z_a measured on the surface reaches a maximum of 1.4 gauss; the depth of the ferrous quartzites below the surface is approximately 150 meters. The quartzites form a series of steeply-dipping beds several hundred meters thick and several scores of kilometers along the strike. With these dimensions at elevations of 1000 meters and more, the magnetic body may be approximated by a double line of magnetic poles, where the separation of the pole-lines is finite.[3] For this case the maximum is expressed by the formula:

$$Z_a = 2\sigma\left(\frac{1}{r-l} - \frac{1}{r+l}\right) = 2\cdot\frac{2\sigma l}{r^2 - l^2} \qquad (1)$$

where σ is the linear density of magnetism, $2l$ the distance between the linear poles, and r the vertical distance from the surface of observation to the center of the layer. If we take σ, $2l$ and r as unknowns, we need at least three equations for finding the values of these unknowns. The data from surface surveys cannot be used, as the concept of linear poles becomes invalid where the plane of observation is so close to the upper edge of the quartzite. We use two profiles at an elevation of 1500 meters, where the observed maxima are 0.22 and 0.225 gauss; and

[2] Atlas kart elementov zemnogo magnetisma (Atlas of maps showing the elements of terrestrial magnetism): Vyp. X, trudy OKKMA, Promizdat 1927.

[3] Bauman, V. I., Interpretatsiya resul'tatov magnitnoi s'emki (Interpretation of the results of magnetic surveys): Bitor 1932 (steklografiya).

three profiles at an elevation of 1000 meters with observed maxima of 0.35, 0.355, and 0.385 gauss.

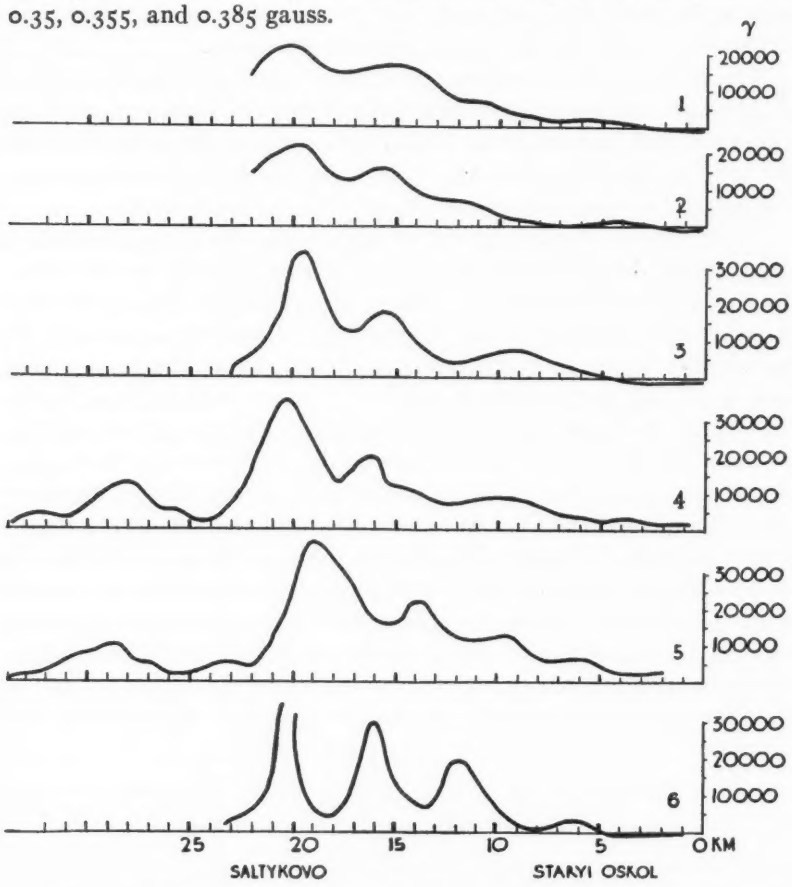

FIG. 1. The Kursk magnetic anomaly in the Staryi Oskol area. Vertical intensity curves along a traverse through Staryi Oskol, Saltykovo, and Kladovoe. Curves 1 and 2 were recorded at 1500 meters above ground level; curves 3, 4, and 5 at 1000 meters; and curve 6 at 500 meters.

We can rearrange equation (1) as follows:

$$Z_a[(r_0 + a)^2 - l^2] = 4\sigma l \qquad (2)$$

where r is the vertical distance of the center of the layer below the ground surface, and a is the elevation of the flight above the ground surface. From this we find the approximate values: $r_0 = 1000$ m., $l = 800$ m., $4\sigma = 1500$ (in absolute units $4\sigma = 1.5 \times 10^5$). By the method of

least squares we derive a correction for the approximate values of and r_0 when l has a set value, such that $r_0 = 1190$ m., and $l = 940$ m.

It is now possible to find a new value: $4\sigma = 1540$, corresponding to corrected values for r_0 and l. Inserting the new value for 4σ, we find: $r_0 = 1040$ m., and $l = 830$ m. These results show that the depth to the upper line of poles lies between 200 and 250 meters, and the depth to the lower line of poles between 1900 and 2100 meters; the distance between them is therefore between 1700 and 1900 meters. The actual dimensions of the orebody may be somewhat greater, as the line of poles will not coincide exactly with the limits of the ore. Leist[4] in his computations uses the law adopted by the Swedish magnetologists, who assume that the distance between the poles is equal to 0.9 times the vertical extent. If we apply this ratio, we obtain the following values for the dimension in question: distance to the upper limit ranges from 100 to 150 meters, and the vertical distance to the lower limit ranges from 2000 to 2300 meters. The known distance to the upper limit is 150 meters. The degree of coincidence of the actual distance with computed values for the distance to the upper limit of the quartzite will also characterize the precision of determination of the lower limit.

We shall now solve the problem of the depth of the lower limit using the known distance of the upper limit (150 meters). Inasmuch as the formula gives only the depth of the line of poles, which generally does not coincide with the upper limit, it is necessary to make an assumption regarding the probable distance between the limit of the body and the line of poles. For solution of this problem let us assume three possible distances between the limit and the linear poles: 0, 50, and 100 meters. Then we obtain:

Distance between upper limit and pole-line, in meters	l	Vertical distance to lower limit	4σ
0	1300	2750	1200
50	1030	2310	1400
100	850	2050	1580

The first assumption should be discarded, as it is scarcely likely that the line of poles will coincide with the upper limit of the magnetic

[4] Leist, E. E., Kurskaya magnitnaya anomaliya (Kursk magnetic anomaly): 1921.

body where the horizontal dimensions of the body are so large compared with the vertical.

On the basis of the two other assumptions, the lower boundary has been determined at 2050 and 2310 meters. More exact calculations are not warranted on the basis of vertical intensity measurements from an airplane. It is possible to estimate the accuracy of the various measurements as roughly $\pm 1000\gamma$; an average value for Z_a as used in the computations naturally will be somewhat more accurate. Granting the possibility of an error of $\pm 1000\gamma$, we solve the problem with a modified value, $Z_a = 0.23$ and 0.35 (in place of 0.222 and 0.363); then $l = 1400$ m., and the depth to the upper pole line becomes 460 meters. When $Z_a = 0.21$ and 0.37, $l = 670$ m., and the depth to the upper pole is 100 meters. The second solution drops out, as it is obviously not possible for the depth of the upper pole to be less than 150 meters. The first solution indicates that the ratio of $2l$ to the vertical dimension of the bed is about 4:5, which holds true for relatively short magnets. The latter consideration in itself does not force us to discard the solution. Another consideration, however, that does appear to invalidate our solution is the fact that the graphic determination of the upper linear pole from the data of surface surveys shows that the depth of the upper pole line is in the order of 200 meters.[4]

Thus a solution of the problem based on extreme values of Z_a, as described above, leads to incorrect results. This indicates that the data from our original calculations are sufficiently reliable, and that the value (2000 to 2300 meters) for the distance to the lower limit of the quartzites is valid.

For our solution of the problem we have manipulated the value of 4σ. The most satisfactory solution seems to be where $4\sigma = 1500$, or $4\sigma = 1.5 \times 10^5$ CGS units. This value is equal to the density of magnetism in a strip one centimeter wide measured across the strike of the bed. If we assume that the magnetic susceptibility k of the quartzites is equal to 1 CGS unit, then $\sigma = 0.5$ CGS units per cm^2. Using this in conjunction with values found from our equations, we determine the width of the beds at 750 meters. However, the value $k = 1$ does not fit the facts; only rarely does k attain the value 0.5, and usually it is considerably smaller.[5] On the other hand, the intensity of the anomaly in the areas examined is undoubtedly due to a large extent

[5] Reikh, Geologicheskye osnovy prikladnoi geofiziky (Geological principles of applied geophysics): Prikladnaya geofizika, vyp. 1, 1936.

to the effect of residual magnetism,[6] the magnitude of which must be several times 0.5 CGS units per cm^2. in order to account for the observed intensity of the anomaly.

We have recently undertaken the measurement of residual magnetism.[7] Unfortunately we had no samples of the ferrous quartzites from the Kursk magnetic anomaly, and consequently we were not able to make a more detailed analysis of the value of σ.

Calculations of the lower boundary of the Kursk ferrous quartzites using the data of surface surveys have been reported by M. V. Yuneev[8] and V. A. Kostitsin.[9] In their calculations, both workers have applied the theory of the magnetic field around elliptical cylinders. Kostitsin has assumed the equivalence of a single cylinder; Yuneev, on the other hand, has employed collections of cylinders to approximate the quartzite beds, adjusting the positions of the cylinders to correspond with individual beds. According to Kostitsin the distance to the lower limit is six to seven kilometers, whereas according to Yuneev it is only two to three kilometers.

The results of our calculations correspond closely with Yuneev's results; our method, however, is distinguished by its extreme simplicity.

[6] Yanovski, B. M., O variatsiyakh elementov zemnogo magnetizma v anomalnom pole (On variations of the elements of the earth's magnetism in anomalous fields): Inf. sbornik po zemnomu magnetizmu i elektr, No. 4, 1937.

[7] Logachev, A. A., Izmereniya magnitnykh svoistv gornykh porod (measurements of the magnetic properties of rocks): Inf. sbornik po zemnomu magnitismu, No. 4, 1937.

[8] Yuneev, M. V., Magnitorazvedka v KMA (Magnetic exploration at the Kursk magnetic anomaly): Fondy TsNIGRI, 1935.

[9] Kostitsin, V. A., Metody opredeleniya polozheniya magnitnykh mass (Methods of determining the location of magnetic masses): Trudy OKKMA, vyp. 1924.

INFORMAL DISCUSSION OF EXPLOSIVES HAZARDS ON SEISMOGRAPH CREWS*

G. M. KINTZ†

ABSTRACT

This paper sets forth the need for a standard set of instructions in the safe handling and use of explosives in the geophysical industry. It suggests the appointments of an agency, such as the Bureau of Mines, to collect data regarding accidents and near-accidents in which explosives were involved, the agency also to analyze the data that are submitted and compile from the data a standard set of instructions. Several accidents which occurred while explosives were being used by the geophysical industry and which were reported to the Bureau of Mines during the last three years are discussed and analyzed in this paper.

Although the accidents analyzed in this paper were not all of the accidents that occurred in the geophysical industry, they cost the industry over $235,000 and the lives of 5 men, in addition to permanent injuries to several members of the geophysical crews. The author believes that if a standardized set of instructions were compiled and used by the geophysical industry, most of the explosives accidents could be prevented. Moreover, these instructions would improve the efficiency of crews when the men are shifted or new men are employed.

COOPERATION OF THE BUREAU OF MINES

For many reasons we of the Bureau of Mines sincerely appreciate the privilege of discussing with the members of this society problems of mutual interest. In the past these discussions have been of material benefit to us in the administration of the Federal Explosives Act, and we hope that they have proved of value to you. We also hope that administration of the Federal Explosives Act has proved to you that the Bureau is endeavoring to serve and not hinder your industry.

Because of the splendid cooperation which the members of your society have given the Bureau of Mines and because of our profound interest in safety, we were glad to accept Mr. Cortes's request to discuss with you informally the accidents that have occurred while explosives were being handled by geophysical parties. In this way it can

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be determined whether we can assist you in assembling instructions that will eliminate circumstances that cause accidents, especially those involving explosives.

SCOPE OF THE FEDERAL EXPLOSIVES ACT

Although the Federal Explosives Act requires the Bureau of Mines to investigate accidents involving explosives, it does not authorize penalties for failure to comply with the safety suggestions made by Bureau of Mines investigators. The responsibility for the enforcement of safety instructions rests with the company, the party chief, and ultimately upon the workers themselves.

LIST OF INJURIES THAT HAVE OCCURRED

Since the Federal Explosives Act became effective three years ago, geophysical companies have reported to the Bureau of Mines the following accidents:

One crew member was very seriously injured because a charge detonated prematurely under very interesting circumstances (case A).

Two men were injured when they endeavored to force past an obstacle in the hole a ½-pound charge of explosives containing a detonator (case B).

One man was seriously injured when the tools of a loading machine, which was being used to knock out a bridge in a hole, struck and detonated explosives in the bottom of the hole, under 30 feet of water (case C).

One man was very seriously injured by the explosion of a detonator he was holding while he attempted to jerk loose the leg wires which had become entangled in a bush as he was preparing to make up a charge (case D).

Two members were injured when they reloaded a hole immediately after it had been shot and the heat detonated the explosives (case E).

One member was killed and one was seriously injured because the wrong wires were connected and a charge on the surface detonated instead of the one in the hole (cases F and G).

Four geophysical-crew members lost their lives because of shooting near power lines (cases H, I, J, and K).

A farm boy was injured while dissecting a detonator that he had pulled from a hole left loaded overnight (case L).

DEFINITION OF "ACCIDENT"

All except two of these accidents occurred in Texas. Similar accidents have undoubtedly occurred in other states but have not been reported to the Bureau of Mines, even though the Federal Explosives Act requires that all explosives accidents be reported.

The failure of companies to report accidents is due in part to the fact that many people do not understand what constitutes an "accident." Webster defines "accident" as "an unexpected or unforeseen event; a nonessential attribute; an incidental feature." Therefore, any unforeseen or unexpected event or incident may be an accident; a fatality, an injury, or property damage is not a prerequisite. If the incident involves explosives, it is required to be reported to the Bureau of Mines under the provisions of the Federal Explosives Act. The main difference between an accident resulting in an injury and one not resulting in an injury is often only a fraction of an inch or a fraction of a minute. If personal injury had not been involved in the accidents mentioned, it is doubtful that they would have been reported.

NEED OF INSTRUCTIONS AND ASSEMBLY OF DATA

The best way to eliminate accidents is to insure that proper instructions are available and that the geophysical crews are well educated in the "whys" and "wherefores" of these instructions. (Note that they are not called "regulations.")

In this room there are 150 people; perhaps there are some who have never handled explosives at all. Several in the audience have handled explosives for over 30 years. Therefore, a safe average to assume would be an experience of 15 years. Thus, if we have 150 people here and we multiply that number by 15, we find that we have a total of 2250 years of experience. You have worked on all types of jobs, in all parts of the country, and in all kinds of weather. Therefore, it is certain that there is in this room more knowledge than could be possessed by any one or two individuals or by any one geophysical company or division of an oil company.

If a central agency would collect, analyze, and assemble the data and confer with experienced representatives of the various geophysical companies, a set of standard instructions that can be used by all companies can be compiled. These instructions could be submitted as a guide to any state, county, or city that might desire to pass an ordinance to control the handling and use of explosives by geophysical parties.

ANALYSES OF ACCIDENTS

As has been stated, the data must be analyzed. There are several methods of analyzing reports of accidents. The following analyses of accident reports submitted to the Bureau of Mines illustrate one method that points out the correct and incorrect procedures, the responsibility for the accident, and the total cost of the accident.

Because case A was the only one discussed at the Dallas meeting and because the items making up the cost of all other accidents, except Case H, would be similar, the cost items are listed for only these two cases.

CASE A: CHARGE DETONATES DURING LOADING OPERATIONS—TEXAS, 1945

A 5-inch hole 60 feet deep had been drilled in limestone and already had been shot twice before—29 days and then 4 days before the day of the accident. On the day of the accident a light rain was falling. Thunder and lightning were occurring in the distance, and static was noted on the radio. A member of the shooting crew was watching the clouds because one company rule stipulates "*During thunder storms:* Keep all explosives in their magazines; see that the trucks are thoroughly grounded; do not park trucks near isolated trees, drill trucks with raised masts, or other isolated high objects; and do not remain near explosives."

As shown in Fig. 1, the radio truck was about 90 feet from the hole and the shooting or dynamite truck about 60 feet from the hole.

Upon arrival at the hole, the second assistant shooter put two 10-pound 2″×27″ sticks of 60% dynamite into the hole and then lowered onto them a third stick containing the detonator.

The primer was made as indicated in Fig. 1, using a loading-pole spike or "stinger" to punch the hole. The detonator was No. 6 with 60-foot nylon-covered wires.

After the primer had been placed in the hole, instructions were received to shoot 60 pounds instead of 30 pounds. The second assistant shooter held the shooting cable in his hand and dropped the fourth 10-pound stick into the hole and felt it land at the bottom, but he did not feel the next two land. Believing that they had lodged in the upper part of the hole and being inexperienced, he called the first assistant shooter and went to the shooting truck. No one knows exactly what the first assistant shooter did, but it is believed that as he lifted the shooting cable the explosives detonated, injuring him seriously.

TABLE 1.—ANALYSIS OF CASE A: CHARGE DETONATES DURING LOADING OPERATIONS—TEXAS, 1945

I. What were the possible causes of the detonation?	II. How could the accident have been prevented?	III. Possible cost of accident to the man	IV. Cost of accident to the company
A. Impact of: 1. Falling explosives against rock, primed cartridge, or detonator 2. Falling rock against primed cartridge or detonator 3. Detonator against rock, caused by jerking lead wires B. Lightning: 1. Wire of shooting line acting as capacitor, causing sparks which ignited explosives C. Detonator pulling out of primer because of too large a punch hole D. Jerking wires, causing bridge in detonator to move (very remote)	A. Avoided impact by: 1. Using loading line or pole; not dropping explosives into hole unless smooth and unless diameter was such that air would retard speed 2. Putting primer in hole last 3. Determining amount of explosives desired before loading hole 4. Shooting primer in hole before additional quantity was added B. Grounded the cable C. Used wooden, bronze, or aluminum punch of proper size D. Not jerked or pulled loading line, especially after primer was loaded into hole E. Ascertained condition of hole by running in loading or gage pole F. Stayed as far away from hole as possible G. Proper education	A. Reduced wages B. Transportation expense to and from doctor during convalescence C. Increased incidental expenses: 1. Recreation while off duty (books, etc.) 2. Special foods 3. Salary for extra household help 4. Entertainment of visitors D. Loss of job experience during convalescence E. Mental and physical pain F. Upset household and family routine	A. Time lost by crew: 1. Taking care of injured man 2. Talking about the accident 3. Preparing reports and answering written inquiry 4. Assisting Bureau of Mines and company representatives in making investigation B. Training new employee C. Compensation (insurance cost) D. Medical expense E. Upset routine (decreased production) F. Time lost by executives and other office personnel G. Legal expenses not covered by insurance cost H. Total cost—4 to 5 times direct cost (compensation plus medical)

The hole had some water in it from previous shots, and the second assistant shooter had washed his hands over the hole between the time of placing the third and fourth sticks into the hole.

The connection between the shooting line and the detonator leg wires was 4 to 5 feet below the collar of the hole. The loading line was

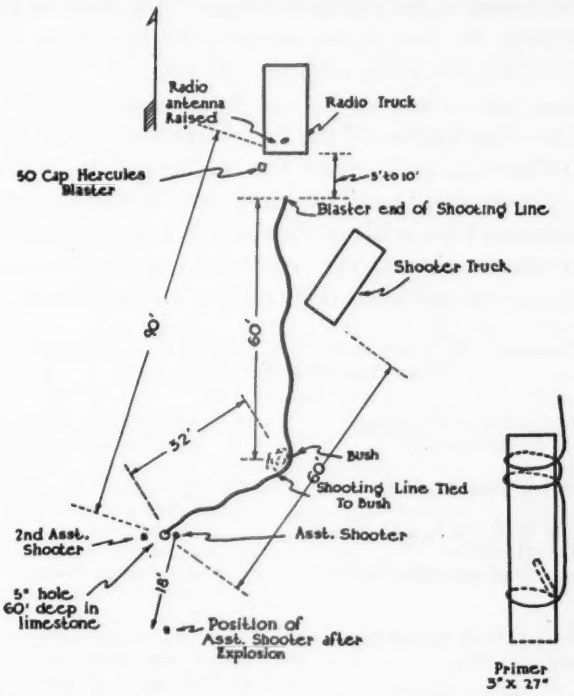

FIG. 1. Disposition of personnel and equipment at time of accident, Case A.

tied to a bush approximately 32 feet east of the hole and was then taken to a point 5 to 10 feet from the blasting machine, and the wires at this end of the firing line were short-circuited. The blasting machine was connected to the radio truck but not to the firing line.

The analysis of this accident, as shown in Table 1, lists the probable causes and the possible means of preventing similar incidents or accidents, as well as supplying other interesting and valuable data.

CASE B: FORCING EXPLOSIVES INTO HOLE—TEXAS, NOVEMBER 1943

A jointed loading pole (1″×1″×10′) with a spear made from an old automobile engine valve on one end was being used to lower a 2½-

pound 2″×24″ primed stick of 60% dynamite into a cased 3-inch seismograph hole. An obstruction was encountered about 7 or 8 feet below the surface. After several attempts to force the explosives past the obstruction by raising and dropping the pole and explosives about a foot, it was decided to remove the charge. As members of the crew started to withdraw it, the charge detonated. Although no permanent injuries resulted, the faces of the shooter and his helper were badly lacerated, and the eyes of the shooter were injured.

The detonator was inserted in the dynamite near the bottom of the stick, and two half hitches of the lead wires were made around the stick. The primer was held against the loading pole by tension on the lead wires. The shooter stated that they were not unduly rough with the explosives and that in his estimation the force used was not sufficient to rupture the charge. The report did not give the depth of the hole, the amount of explosives to be shot, or the fluid level.

TABLE 2.—ANALYSIS OF CASE B: FORCING EXPLOSIVES INTO HOLE—ARKANSAS, NOVEMBER 1943

I. What were the possible causes of the detonation?	II. What could have been done to prevent the accident?
A. Rough or improper handling of explosives: 1. Dropping loading pole with primed cartridge attached 2. Forcing primed cartridge into hole	A. Handled explosives properly: 1. Not forced primed cartridge 2. Measured hole when obstacle was encountered to determine if there was sufficient clearance 3. Used other means of lowering explosives into hole
B. Frictional contact of dynamite with steel stinger or casing	B. Avoided frictional impact: 1. Not used spike on end of pole 2. Used spike of soft, non-sparking material if one was necessary
C. Dropping pole and primed cartridge jarred detonator out of cartridge, causing detonator to strike or scrape against casing	C. Securely fastened detonator in place and not dropped or jarred primed cartridge
	D. Determined condition of hole by running gage pole into cased or uncased hole prior to loading
	E. Conducted job and safety training courses in proper handling of explosives

CASE C: KNOCKING OUT BRIDGE IN HOLE—TEXAS, JULY 1945

Two hundred and forty pounds of explosives had been loaded into the bottom of an 85-foot hole which bridged at 45 feet. The loading machine was used to knock out the bridge. After the bridge had been loosened, it was pushed to the bottom of the hole by the falling tools.

When the tools struck the bottom, the explosives detonated, although there was no detonator in the charge which was under 30 feet of water. The attendant's forearms were cut and bruised by the rocks driven from the hole.

Analysis of this case is shown in Table 3.

TABLE 3.—ANALYSIS OF CASE C: KNOCKING OUT BRIDGE IN HOLE—TEXAS, JULY 1943

I. What was the possible cause of the detonation?	II. What could have been done to prevent the accident?
A. Heavy loading tools falling approximately 40 feet and striking explosives under 30 feet of water	A. Used loading machine properly: 1. Used loading machine for the purpose for which it was made 2. Used proper tools for knocking out bridge 3. Shot bridge with small charge B. Instructed and trained shooting crew in safe handling of explosives

CASE D: JERKING LEAD WIRES—TEXAS, NOVEMBER 1943

An employee was preparing to make up a charge for a weathering shot at the hole some distance from the blasting machine and explosives. He held the detonator in his left hand and tossed the folded detonator lead wires away from him. The wires became entangled in a

TABLE 4.—ANALYSIS OF CASE D: JERKING LEAD WIRES—TEXAS, NOVEMBER 1943

I. What were the possible causes of the detonation?	II. What could have been done to prevent the accident?
A. Striking detonator against auger handle B. Jerking wires, causing movement of wires inside detonator (Remote) C. Loose seal—defective detonator (Remote)	A. Observed surroundings and performed operations away from objects B. Not jerked or pulled wires of detonator C. Strung out wires; unwound leads as charge was lowered into hole D. Handled detonator carefully E. Instructed and trained shooting crew in safe handling and use of explosives

bush, and when he attempted to jerk them loose he either jerked the wires in the detonator itself or struck the detonator against an auger handle that was standing upright beside the hole. The employee suffered the loss of a portion of his thumb and second finger.

CASE E: RELOADING HOLE TOO SOON AFTER PREVIOUS SHOT—TEXAS, FEBRUARY 1943

The 200-foot hole already had been shot once during the day. The second charge was being loaded, and 200 pounds had been placed into the hole. As additional 10-pound sticks of dynamite were being dropped into it, the heat in the hole caused the explosives to detonate. Sand was blown into the face of the shooter and the helper, and each suffered a ruptured eardrum by the concussion of the explosion. Previously a detonation had occurred in this same hole because explosives had been placed in it too soon after the preceding shot.

TABLE 5.—ANALYSIS OF CASE E: RELOADING HOLE TOO SOON AFTER PREVIOUS SHOT—TEXAS, FEBRUARY 1943

I. What was the possible cause of the detonation?	II. What could have been done to prevent the accident?
A. Heat in hole detonated the dynamite	A. Determined that hole was cool enough for reloading: 1. Allowed sufficient time for hole to cool 2. Used water tamping if necessary to shoot hole more than once a day 3. Taken temperature of hole if more than one shot fired B. Shot only one shot a day in hole C. Instructed and trained shooting crew in safe handling and use of explosives

CASE F: CONNECTING WRONG WIRES—TEXAS, APRIL 1943

Because the ground in the vicinity of the hole was sandy, the procedure was to make up two charges of dynamite and have the second one ready to load as soon as the previous shot was detonated. Two separate firing lines were being used in this operation—one attached to the charge in the hole and the other to the charge on the surface about 5 feet from the hole.

On the day of the accident the shooting crew comprised the shooter and his helper, and the shooting truck was parked approximately 10 feet from the shot hole. While waiting for the recording crew to set up their instruments, the shooting crew made up the second charge of 10 pounds and placed it about 5 feet from the hole. The assistant was sent out to the road to warn any cars, and the shooter connected the battery with the line of the charge on the surface instead of with the line of the charge in the hole. He was 20 feet away from the charge when the detonation took place, and the blast injured his right ear.

TABLE 6.—ANALYSIS OF CASE F: CONNECTING WRONG WIRES—TEXAS, APRIL 1943

I. What was the possible cause of the detonation?	II. What could have been done to prevent the accident?
A. Connecting wrong firing line to the blasting machine	A. Allowed only one shot firing line B. Checked all connections and traced the lines before firing C. Taken minimum amount of explosives from magazine: 1. Permitted only enough explosives for one shot to be removed from magazine 2. Not permitted second charge to be made up until first charge was fired D. Allowed only one detonator at a time out of portable magazine during shooting operations E. Cased hole F. Instructed and trained shooting rew in safe handling and use of explosives

CASE G: CONNECTING WRONG WIRES—TEXAS, MAY 1944

The shooter and his assistant prepared a charge of 100 pounds of Nitramon and lowered it into a hole 230 feet deep. As another shot in the same hole was anticipated, a second charge of 19 pounds of Nitramon was made ready and placed on the ground about 40 feet south-

TABLE 7.—ANALYSIS OF CASE G: CONNECTING WRONG WIRES—TEXAS, 1944

I. What was the possible cause of the detonation?	II. What could have been done to prevent the accident?
A. Connecting wrong line to firing unit	A. Allowed only one firing line B. Checked all connections C. Taken minimum amount of explosives from magazine: 1. Permitted only enough explosives for one shot to be removed from magazine 2. Not permitted second charge to be made up until first charge had been fired D. Allowed only one detonator out of portable magazine at a time E. Stood some distance from exposed explosives during blasting operations F. Shot from outside of truck so that lines could have been seen and hole observed . Conducted instruction classes for shooting crew in safe methods of handling explosives

west of the shooting truck. The assistant went to the shooting truck, and the shooter brought the firing lines (which were supposed to have been connected to the charge in the hole) to the truck and hung them on the door handle of the truck. The assistant asked the shooter if the wires he had brought were the ones connected to the ones in the hole, and the shooter stated that they were. The assistant connected the firing wires to the blasting machine in the cab of the truck and called the observer. The shooter returned to the place where the primer and the 19 pounds of Nitramon were lying on the ground. Upon word to fire, the assistant operated the blasting machine, firing the charge on the surface, and the shooter was killed when the primer near him detonated.

CASE H: SHOOTING NEAR POWER LINES—TEXAS, SEPTEMBER 1942

A hole about 29 feet from a high-voltage power line and 49 feet deep was loaded with 5 pounds of explosives. The wind was blowing from the power line toward the hole, so sufficient slack had been left

TABLE 8.—ANALYSIS OF CASE H: SHOOTING NEAR POWER LINES—TEXAS, SEPTEMBER 1942

I. What was the possible cause of the accident?	II. What could have been done to prevent the accident?	III. What was the cost of the accident?
A. Firing line blowing over high-voltage power line	A. Located hole safe distance from power line B. Used as short a firing line as possible—not long enough to reach from snubber to power line C. Used snubber so located as to whip firing line away from power line D. Used Primacord E. Not depended on wind to blow wires F. Located shooting truck and blasting machine at position other than between hole and power line G. Chief of party, or person other than shooter, taken personal charge in shooting all holes near power lines and other dangerous locations H. Trained crews thoroughly and properly in safe handling of explosives	A. Two lives B. Ambulances C. Funeral and undertaker D. Transportation cost of bodies and family E. Time lost by crew: 1. Remainder of day of accident 2. Time to take care of dead men 3. Time spent in talking about accident 4. Compiling and writing reports of accident 5. Assisting Bureau of Mines and company representatives in making investigation F. Total coast generally considered 4 to 5 times actual compensation cost. (Texas allows $7,000 for a fatality.) (See also Table 1)

to permit the line to drift with the breeze. It is believed that the assistant shooter was electrocuted when he became entangled in the wires, causing them to be thrown across the power line, and that the shooter was electrocuted by the high-voltage current which charged the telephone that he was holding. The shooting truck and the blasting machine were between the hole and the power line. The men in the recording truck, hearing the static and seeing sparks on the reel, rushed to the hole but were unsuccessful in their attempts to revive the shooter and his assistant by means of artificial respiration.

The location of this hole had been discussed by the shooter and the members of the party. Because he had previously fired holes close to the power lines, the shooter was confident that he could shoot this one without a mishap.

CASE I: SHOOTING NEAR POWER LINES—TEXAS, APRIL 1943

The shooter was killed and the observer injured, but not seriously, when slack firing lines leading from a blasting machine to a detonator in a hole were blown into the air and dontacted a power line.

The hole was about 4 feet east of one of the wires of a power line, 26 feet above the ground, transmitting 11,000 volts. The 5-pound charge of 60% dynamite had been prepared by punching a hole approximately 4 inches from the top of the charge and then running standard Primacord through the hole and tying a knot. A No. 6 electric detonator with 60-foot lead wires was fastened to the opposite end of the Primacord by a knot and friction tape, and the charge was lowered into the hole by the Primacord. The upper end of the Primacord with the detonator attached was 10 to 15 feet from the top of the hole when the charge was at the bottom of the 70-foot hole. The shooting truck was approximately 70 feet from the hole. The 60-foot lead wires of the detonator were fastened to the end of the firing line, leaving 45 to 50 feet of the lead wires on the surface near the hole. This, with 10 feet of slack in the firing line, left 55 to 60 feet of slack wires between the top of the hole and the blasting machine.

After the hole had been loaded, the shooter and his helper went to the blasting machine alongside the shooting truck. When the instructions had been received, the shooter turned the firing handle on the blasting machine and at the same time short-circuited the telephone. The helper was on the opposite side of the truck and was facing the hole. Immediately after the blast the helper saw fire flash from the power line and heard the shooter cry. He rushed to him and found that he had fallen from a squatting position to his side. The

helper grabbed the blasting machine, threw it away from him, and applied artificial respiration but was unsuccessful in his attempt to revive the shooter.

TABLE 9.—ANALYSIS OF CASE I: SHOOTING NEAR POWER LINES—TEXAS, APRIL 1943

I. What was the possible cause of the accident?	II. What could have been done to prevent the accident?
A. Shooting lead wires from hole against 11,000-volt power line	A. Located hole properly: 1. Instructed surveyor regarding location of hole near power lines 2. Instructed drilling crew regarding drilling holes near power lines 3. Instructed shooter in hazards of shooting holes near power lines B. Eliminated all slack in firing line from detonator to blasting machine C. Properly anchored or snubbed firing line D. Party chief, or person other than shooter, should have taken personal charge of shooting all holes near power lines or at other dangerous locations E. Trained crews thoroughly in proper and safe handling and use of explosives

CASE J: SHOOTING NEAR POWER LINES—ARKANSAS, JANUARY 1944

A 50-foot hole was located about 12 feet from the highway and 25 feet from the place where a 7,000-volt, 3-wire power line crossed the road at an angle. Three shots already had been fired in the hole, two of them with $2\frac{1}{2}$ pounds and the other with 5 pounds. The fourth shot, a 5-pound charge of 60% dynamite, was fired at a depth of 40 feet, with 40 feet of shooting cable in the hole and 10 feet of slack on the ground.

The force of the shot blew the cable from the hole over the power line at a point where it crossed the road. In order to remove it from the highway and the power line, the shooter disconnected the shooting cable from the shooting truck parked underneath the power line and succeeded in twisting the opposite end of the cable around a stick 1 foot long. He then walked backward across the highway, dragging the cable across the power line, and fell backward into a ditch 4 feet wide and 14 inches deep and full of water. As he fell he jerked the cable into the water with him and was electrocuted. The cable was insulated with heavy rubber, but at the time of the accident it was covered with slime and mud blown out of the hole by the three previous shots. None of the crew members had had first-aid training, but they stated that the shooter was dead when they reached him.

TABLE 10.—ANALYSIS OF CASE J: SHOOTING NEAR POWER LINES—ARKANSAS, JANUARY 1944

I. What was the possible cause of the accident?	II. What could have been done to prevent the accident?
A. Shooter, pulling firing line off power line, fell into ditch filled with water	A. Had power company remove firing line B. Located hole properly: 1. Instructed surveyor regarding location of hole near power lines 2. Instructed drilling crew regarding drilling near power lines 3. Instructed shooter in hazards of shooting near power line. (Some companies forbid the locating of hole near power line.) C. Permitted no slack in line from detonator to blasting machine D. Used properly located and installed anchors or snubbers E. Used Primacord, with lead wires from mouth of hole to detonator as short as possible F. Party chief, or person other than shooter, should have taken personal charge of shooting of all holes near power lines or other dangerous locations G. Used proper electricians' tolls if wires must be pulled from power line H. Conducted job or safety training and education program in safe handling and use of explosives

CASE K: SHOOTING NEAR POWER LINES—MISSISSIPPI, MAY 1944

A hole across a road, approximately 40 feet from a power line 25 feet above the ground, was shot at a depth of 50 feet. Although the company had issued instructions never to shoot near a power line unless Primacord was used, the shooter fired the charge without it, probably because the party did not have any Primacord with them at the time.

The party chief was not advised by the engineer, the shooter, or the observer that the hole was near a power line. He should be praised for reporting this case, as no one was seriously injured; his sincere interest in preventing a similar incident is indicated by the following statement: "Our company has issued instructions that Primacord should be used at all times when shooting anywhere near a transmission line. The shooter has used Primacord in the past and is posted on the regulations. I will personally inspect our proposed lines on future work and make sure that necessary precautions are taken. This ac-

cident is the result of violation of company regulations and also Bureau of Mines regulations and demonstrates extreme carelessness of the above mentioned crew members."

Except for minor burns on the thumb and finger of the shooter, no employee sustained injuries when the cap leads were blown across the transmission line.

As no other details were given in the report, the accident could not be analyzed beyond the fact that a company rule was disobeyed; the crew members had not been properly trained in the possible hazards of shooting near a power line, or they deliberately disobeyed instructions. If the party chief had been personally supervising this shot, the incident probably would not have occurred.

CASE L: CHILD INJURED BY DETONATOR TAKEN FROM HOLE—TEXAS, OCTOBER 1944

For recording purposes the crew had shot a charge in one direction and, because of caving shot-hole conditions, had reloaded the hole for shooting a set-up in the opposite direction. Since there were to be other recordings, the hole was left charged to be shot the following day.

After the party had left the field, a farmer boy went to the hole and pulled the lead wires and detonator from the hole and took them home. He dissected the cap with a pair of scissors and burned the powder. He then applied the flame of a match to the shell of the detonator which exploded, fracturing and lacerating the little finger of his left hand and sending slivers of copper and wood into his face, arms, and body.

A tabulated analysis of this accident is not necessary, as the cause was either improper supervision or improper instructions, or both. Regulations of the Federal Explosives Act require that "All explosives and ingredients of explosives must at all times be safely stored and handled and adequately protected against theft."

CONCLUSION

Geophysical companies using explosives in Texas and Arkansas during the last three years have been required by the compensation laws to pay over $47,000.00 in compensation; actually the cost was approximately five times that amount. The approximately $235,000.00 is negligible compared with the cost of five or six lives, loss of hearing in one ear, loss of portions of two fingers, and other injuries and suffering, in addition to the loss of valuable man-hours of work.

Neither the geophysical nor any other industry can afford the heavy costs of accidents. Do not these losses prove that there should be a set of standard instructions for handling and using explosives in the geophysical industry and that there should be a plan of educating the members of geophysical parties in the "whys and musts" of such a set of instructions and that all premature explosions or unforeseen incidents involving explosives should be reported?

If all geophysical companies and all parties of a geophysical company would handle explosives in accordance with a universally accepted set of standards, it would reduce not only accidents but also the necessity of training an employee transferred from another company or party.

Perhaps some who read this article will not fully agree with all the statements in the analyses of the accidents. If so, the author would appreciate a letter from them stating their thought, because only through frank and open discussions of these kinds of incidents can a final, practical, and safe method satisfactory to the majority of persons concerned be obtained. If any person knows of other accidents that occurred while geophysical parties were using explosives, it would be appreciated if he would submit the details of the accidents to the author so they may be analyzed and the causes publicized.

Bureau of Mines engineers are available to assist in compiling a set of standard instructions or to act as a central agency for such a compilation and to aid in the education of crew members in the safe handling of explosives.

GEOPHYSICAL OPERATIONS IN KUWAIT*

P. H. BOOTS† AND ALEXANDER H. McKEE‡

ABSTRACT

This paper describes the general operations of the combined geophysical party, using gravity, magnetic and seismic methods, which made a survey of Kuwait in one working season. The organization of the party, the general conditions met, and the manner in which the operations were adapted to the country and its people are described. The geophysical results themselves are not included, but it may be remarked that the surveys described led to the discovery of one of the great oil fields of the world.

INTRODUCTION

This article describes a survey that was made of Kuwait (in the Persian Gulf area) in a successful search for oil. The methods applied to the search in Kuwait are equally applicable to the major portion of the Near and Middle East with results that may quickly and economically disclose the prospects of the area. No new methods will have to be developed for such a search. The tools that have been tried and proven in this country in the past few years are adequate for the job.

It is hoped that this review of the survey of Kuwait will serve to illustrate how a well-rounded geophysical attack, using the rapidly moving gravimeter and magnetometer for reconnaissance, followed by seismograph work in selected areas, and with competent and close geological cooperation, can give immediate and positive results in an entirely new area.

LOCATION, TOPOGRAPHY, AND CLIMATE

Kuwait lies at the northern end of the Persian Gulf at Latitude 29°N. between Iraq to the north and Saudi Arabia to the south and west (Fig. 1). The eastern boundary of Kuwait is formed for 145 kilometers by the Persian Gulf. The area of the country is 12,250 square kilometers or about 4,730 square miles. It is ruled by the Sheikh of Kuwait, Sir Achmed ibn Jabur as Subah.

The topography of Kuwait generally is of low relief (see topographic contours, Fig. 1). From the Persian Gulf shoreline, the land

* Read at the meeting of the Society, Dallas, Texas, March 21, 1944.

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rises gently to the westward to an altitude of 280 meters. Forming the western boundary is an abrupt break, a long narrow trough about 5 kilometers wide and 100 meters deep known as Al Batin. The maximum depth of Kuwait Bay is fifteen fathoms and large areas are exposed at low tide. From Kuwait Bay south, the shore line is closely paralleled by a ridge, Al Tha'ar, of about 100 meters relief.

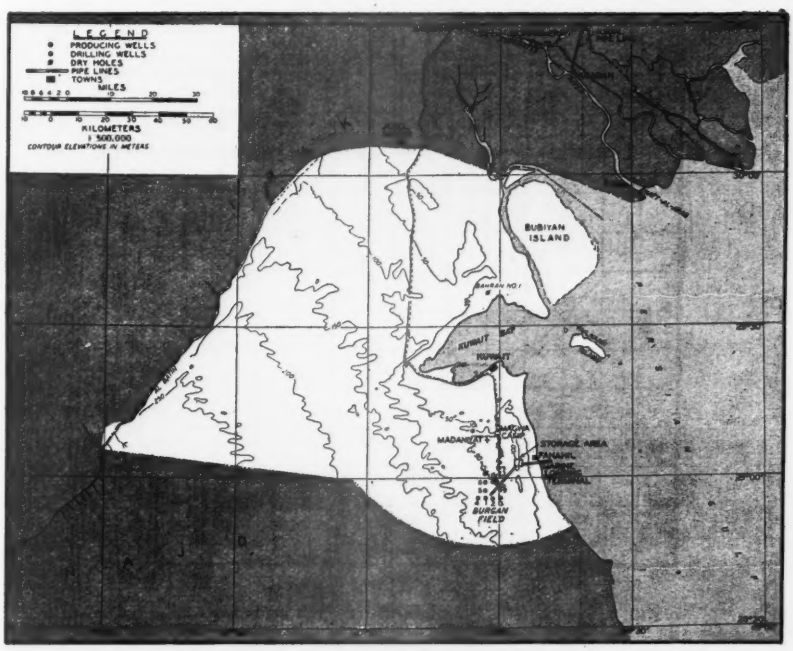

FIG. 1. Index map, showing location of Kuwait, wells (as of mid-1945), and topographic contours (from geophysical survey data) at 100 meter interval. (Courtesy Oil and Gas Journal.)

There are no permanent streams in Kuwait. The low hills are separated by wide, shallow, and sandy watercourses, dry except during an exceedingly rare heavy shower. Large areas in the northern and western parts of the country are covered by typical aeolian gravel. These areas are excellent for car and truck travel and, over them, it is possible to drive unhindered in any direction. Other areas have a low sagebrush-like perennial called camel thorn. Around the base of this bush, sand collects in hummocks, which slows truck travel exceedingly.

The climate is controlled by winds that have had all the water wrung out of them in their long sweep across Asia before they reach Kuwait. It is hot and dry in the summer and generally dry and cool in the winter. The humidity is very low except for a few days in the winter and spring. There is a daily temperature range of 20 to 25 degrees. The annual maximum and minimum are about 125 degrees and 30 degrees Fahrenheit. Both the daily and annual cycles of temperature are quite regular. (Fig. 2) There are rather strong winds at

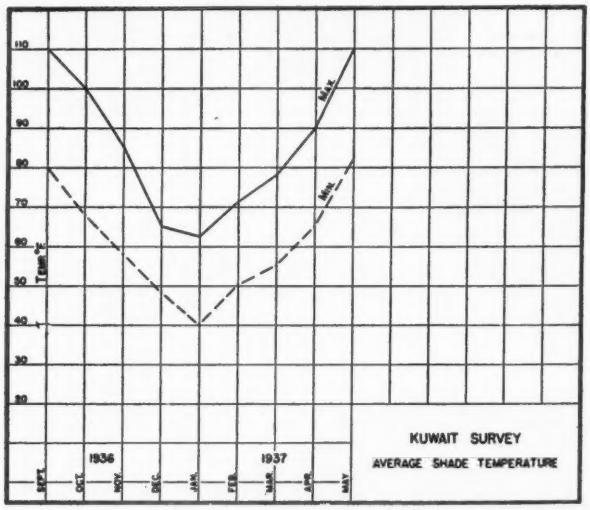

FIG. 2. Average daily temperatures, 1936–1937, as recorded by geophysical party.

random times throughout the year but, in the early summer, extreme winds blow for days, generally from the north. Once or twice during January, the temperature drops low enough to form a thin layer of ice in the camp water pans.

An annual precipitation of about four inches usually falls in a few heavy showers (sometimes accompanied by much lightning) in the winter. After one of these rains, the desert is very muddy for a few hours and the normally dry watercourses give the appearance of having been raging torrents at the height of the storm. During the summer there are days and weeks when there is not a cloud in the sky. Then the sun temperatures are extreme and the days are very monotonous. Thus, late fall, winter, and early spring provide pleasant working conditions, but the same cannot be said for the rest of the year.

PEOPLE AND CUSTOMS

Kuwait has a population variously estimated from 50,000 to 75,000. Probably ninety per cent of the people live in the walled city of Kuwait located on the south shore of Kuwait Bay. Modern improvements and conveniences have not yet infiltrated. The town has no water system whatever and, consequently, no sewage system. It does have an electric plant and a limited distribution system, but it is in operation only a few hours out of the twenty-four. No hotel is available for the visitor from the Occidental world. Streets are narrow and, in most cases, have just enough clearance for the occasional automobile that drives through them.

The lack of an adequate local water supply makes the town dependent upon water shipped sixty miles by sailboat from the Shatt-el-Arab, the river formed by the confluence of the Tigris and Euphrates in lower Mesopotamia, and distributed through the town on the backs of donkeys.

There are several small oases near the coast which depend on well water and manage to irrigate vegetable and date gardens from this source. These oasis wells are large pits 15 feet square and 25 to 40 feet deep employing goat-skins and donkey power combined in an ingenious manner to lift the water to the surface. It is rumored that an American-type windmill once graced an oasis well, but it had fallen into disrepair and disuse. No trace remained.

A few hundred people live in oases. A varying number of Bedouins (nomadic sheep and camel herders) populate the desert hinterlands. These people migrate with their flocks to follow pasturage. In the winter, the flocks are driven far from the wells to allow the grass to grow there. As the hot weather approaches and the animals must be watered more often, the flocks come closer and closer to the wells and the dried grass near them is used for pasture. The pasture does not follow national boundaries and neither do the Bedouins. This seasonal wandering of the Bedouins follows certain patterns dictated by weather and by customs hundreds of years old. Thus, there may be several thousand Bedouins in Kuwait at some seasons, at other times almost none. For the most part, they are quite friendly and hospitable, sometimes inviting one to partake of coffee at their nearby tent.

PURPOSE AND ORGANIZATION OF GEOPHYSICAL PARTY

The interest in Kuwait from the point of view of petroleum was probably initiated by two or three small oil seeps in the country. The Sheikh of Kuwait granted a concession of the oil rights of the country

to the Kuwait Oil Co., Ltd., in 1934. A geological survey of the area was made, but little surface evidence of structure was observed. The problem was that of assessing the possibilities of the country. Little was known of the geologic section. The nearest oil wells were in Iraq, Iran, and at Bahrein, none of them close enough to disclose the section in Kuwait. It was decided to drill a test hole on the limited surface evidence of structure that had been observed north of Kuwait Bay and at the same time make a geophysical survey of the country. If the hole were dry, it would at least disclose the section. If the hole made an oil well, the geophysical survey should disclose the extent of the structure on which the well was drilled. The test, Bahrah No. 1, was begun in 1936.

Because of the remoteness and inaccessibility of Kuwait, it was decided that the country should be covered by some kind of reconnaissance geophysical survey in one working season which was judged to extend from September through May. As there was no advance way of knowing what methods would work best in Kuwait, it was decided to make the geophysical party as versatile as possible so that the maximum results might be gained from the effort expended. The party was to be equipped to do gravity, magnetic, and seismic work.

Three magnetometers were assigned to the party. These were Schmidt vertical balances that had been used for some time in work in this country and South America. One of these instruments was to be used as a base instrument, one as a field instrument, and the third as a spare.

Two standard Gulf gravimeters[1] were allotted as gravity field instruments. Small portable gasoline powered generators were used to charge the batteries for maintaining temperature control of these instruments.

Standard seismograph equipment adaptable to doing either reflection or refraction work was mounted in a truck with a false roof, thus affording the operator additional protection from the sun. The drill for seismic shot holes was made up to special specifications and was much heavier than normal so that it could be used also for drilling 800′ or 900′ holes for water wells or for core drill tests.

All automotive equipment was of one make and all trucks were held to two models, with the exception of the drill chassis, to simplify repair problems. All units were equipped with oversize wheels and tires

[1] R. D. Wycoff, *The Gulf Gravimeter*, GEOPHYSICS, 6, No. 1 (Jan. 1941), pp. 13–33.

because part of the area had been reported to be quite sandy. (Fig. 3)

Spare parts to cover almost any eventuality were assembled for both the automotive and geophysical equipment. This spare assembly was based on former foreign working experience. Shipping time to Kuwait was so great that the breakdown of a really critical part could shut down a unit long enough to prohibit the completion of the survey in one season. Although it was not expected that all of the spare parts would be used, they were looked on as insurance against failure to

FIG. 3. Motor equipment for Kuwait survey, as assembled at Gulf Research Laboratories, for shipment to Kuwait.

complete the survey in one season. A complete automotive repair shop was included.

The personnel of the party was selected with the idea that both the gravity and magnetic methods would not be used as reconnaissance over the entire country. Both were to be tried, then the one that showed the more promise would be used to complete the survey. It was fairly certain that the seismograph would be used because it is a rare area that will not yield some information to either the reflection or refraction methods of survey. The men for the party were accordingly selected with the idea that they would have to be able to use more than one kind of instrument. Also, the men were so selected that if any given man became ill or had to leave the country, he could immediately be replaced by another man so that the work could go on. The personnel of the party was

2 magnetometer operators
2 gravimeter operators
1 seismic interpreter
1 seismic observer

1 driller
1 shooter
1 draftsman
4 surveyors
1 mechanic-driller
1 party chief

The camp equipment such as tents for living quarters, kitchens, offices, and so forth, was furnished by the local operating company. The office and kitchens were wood buildings made in sections so that they could be quickly dismantled and transported from campsite to campsite on a ton-and-a-half truck. The living quarters were 12′×16′ tents

FIG. 4. General view of Geophysical Camp.

(made in India) of several thicknesses of thin cotton cloth. Doors and window flaps in these tents served to make them as wind and dustproof as tents can be (Fig. 4). For desert use they were superior to any tents seen in this country, but would be unsuitable for use in tropical countries where the humidity is high.

The camp was furnished with electricity by a 1½ kilowatt, 110 volt d.c., gasoline driven generator. The kitchens were furnished with kerosene operated refrigerators. A shower room was constructed complete with hot and cold running water. The water came from two large drums supported overhead and, in cooler weather, charcoal burning in a central flue in one of the drums provided the hot water. These modern conveniences added much to desert living. The camp personnel consisted of Indian cooks and mess boys with natives for general camp chores.

GENERAL METHODS OF OPERATION

Prior to the geophysical survey, no ground survey had ever been made of Kuwait. Thus, the party had the opportunity of starting from

scratch. An approximate outline of the country was available and a former British Political Agent had made a reconnaissance sketch showing the most prominent land features and place names. The British Admiralty had a hydrographic survey of Kuwait Bay and its approaches. The surveying problem in Kuwait called for the establishment of primary control, laying out seismograph control, locating and leveling gravity stations, and locating magnetic stations within the basic primary control.

The primary control was established with a reasonably precise transit by triangulation from a carefully chained base line. The drilling well, Bahrah No. 1, was utilized as the origin of the metric coordinate system which was adopted for the work. Triangulation stations were established on prominent landmarks and at convenient intervals throughout the country. These triangulation points were kept to an accuracy of not less than one in five thousand which was considered sufficiently precise for any work the oil company might wish to do. Seismic profiles were tied to the triangulation net by chained lines. Seismic elevations were run using transit vertical angles in trigonometric leveling.

Gravity and magnetic stations were located by plane table using triangulation or stadia traverse methods. These stations were located in a regular square array on the metric grid. The plane table operator would establish a corner on this grid from the primary control, orient himself and measure by speedometer (all vehicles had metric speedometers) the distance to the next station location. By observation on signals on primary control points, he would cut in his location and make a stadia shot to the station position. In this way, the plane table work was seldom carried long distances without benefit of primary control.

In that monotonous landscape, the absence of any prominent points on the horizon makes it difficult to drive a car in a straight line. After some experimentation, improvised sundials were mounted on the car radiators and used as sun compasses. By watching the shadow on the dial and keeping it properly oriented, one was able to maintain a reasonably straight course in any desired direction.

The levels for the gravity stations were carried with Y-levels in the usual manner. All stations were on closed traverses and a closure of 10 cm. or less was demanded on all loops. Sea level was established by a short series of observations on high and low tide marks. This was not an accurate determination because the level of the Persian Gulf

depends to a great extent on the direction of the wind. However, this is an unimportant point because an error in the datum plane does not affect the validity of the results of the geophysical survey. A by-product of this survey of Kuwait was a topographic map of the country accurate within the limits of the density of the elevation control.

GRAVIMETER AND MAGNETOMETER OPERATIONS

The geophysical party and its equipment landed in Kuwait in the middle of September, 1936, during very hot weather. Equipment and supplies were taken off ship and the equipment uncrated, assembled, and tested in the following two weeks. Also, Arab labor was hired; truck drivers were tested for their ability. Some interpreters were acquired in an effort to overcome language differences.

Gravity, magnetic, and seismic work was all started at the drilling well, Bahrah No. 1, on October 1, 1936. The gravity and magnetic work was started with station spacing of 1 kilometer on a rectangular grid. This spacing was of an experimental nature because the size of the anomaly to be expected was not known. After about 900 square kilometers had been worked, it became apparent that the gravity and magnetic pictures were sufficiently regular that the station spacing could be doubled without missing any essential features. Furthermore, from the rate of progress, it had become apparent that the country could not be covered in one season with either instrument with a 1 kilometer spacing; however, this was a secondary consideration in opening up the spacing. Early in December, the spacing was increased to 2 kilometers and held there for the remainder of the survey with the exception of selected areas where closer spacing was used to check results.

A two months' trial of the two kilometer spacing showed that both the magnetometer and gravimeter could not cover the entire country in the remainder of the working season. An inspection of the results from both methods also showed that the gravity was probably giving the more information of the two methods, although both were yielding gratifying results. Magnetometer work was then abandoned and the released personnel added to the gravity survey. Unfortunately, at this time, one of the gravimeter operators became ill and had to return to the States. Two additional surveyors were hastily sent from the States to help with the location and leveling of gravity stations to assure completion of the survey.

Fig. 5 shows the rate of progress of the gravity and magnetic work. It will be noted that the number of magnetic stations taken per day was relatively constant throughout the survey, whereas the number of gravity stations occupied per day tended to increase throughout the survey. The explanation is that the magnetometer is essentially a one-man instrument, and the operator was already experienced when the survey began. He was able to occupy stations at a fairly constant rate once the survey was under way.

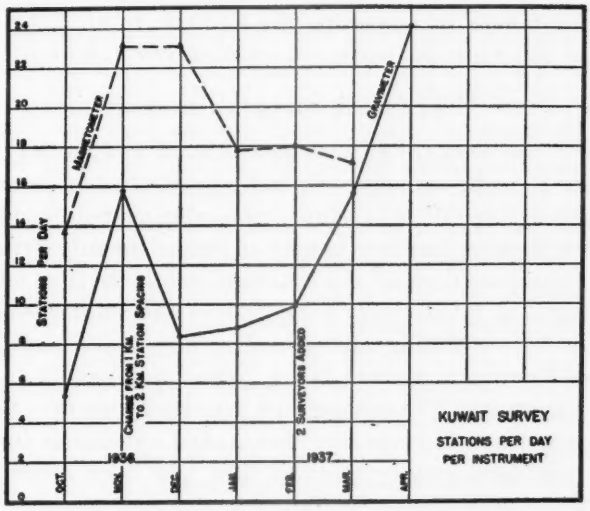

FIG. 5. Daily output (per instrument) of magnetic and gravity stations.

Each gravimeter required two men for its operation, one American and his Arab helper. It took more than a month to train this helper in his duties. At the end of the second month, the gravimeter could occupy more stations than the surveyors could furnish, as the surveyors were also training green men at the same time and their training was more difficult than that of the gravimeter helper. In November, three times as many stations were occupied as in October, the first month of the survey. In December, the rate dropped back to about one-half of the November rate which reflects the change in station spacing from one to two kilometers. For three months, there is a slight increase in the curve which reflects the added training of the surveying crews. In February, three surveyors were added to the grav-

ity staff. The rate then rises steeply through March and April, reflecting the training of the new crews, who, incidentally, learned faster than the original crews because experienced Arabs were seeded with the new men and language difficulties were eliminated to a great extent.

This graph indicates that the gravity survey was just hitting its true stride when the job was completed. This is about the training period that might be expected in an operation of this kind. An experienced party with two gravimeters should be able to occupy about 1,500 stations per month in a country like Kuwait. In all 2,257 magnetic streets and 4,442 gravity stations were observed in Kuwait.

SEISMOGRAPH OPERATIONS

The first two weeks after seismograph work was started in Kuwait on October 1, 1936, were spent in testing instruments, in experimental shooting, trying different setups, measuring near-surface velocities, shooting short refraction lines to gain an idea of the sub-surface velocities, and determinations of the optimum depth for shot holes. After three months of rather slow work around the drilling well, during which time Arab drilling and recording crews were learning their duties, the location of Bahrah No. 1, looked unfavorable from a geophysical standpoint. The seismograph activities were then transferred to an area south of Kuwait Bay that looked anomalous from the results of some 400 gravity stations that had been observed there. Bahrah No. 1 subsequently proved to be dry.

Four months' seismic work was completed south of Kuwait Bay. The shooting was slow because of the difficulty experienced in drilling shot holes even with the heavy drill employed. Nevertheless, a structural area of interest was outlined and detailed sufficiently to secure a satisfactory drilling location. This location, Burgan No. 1, was subsequently drilled in as the discovery well of the Kuwait field.

It should be stressed that the interpretation of the whole survey of Kuwait was aided by the resident geologist who was not only well acquainted with the geology of the Persian Gulf Region, but also well versed in geophysical methods. He was in weekly and sometimes daily contact with the party. In this way, interesting results could be sympathetically discussed and acted upon as they were mapped. This cooperation avoided the lost motion that often develops in foreign work where results sometimes spend weeks in the mail before they can be discussed from the geologist's point of view.

COOPERATION WITH NATIVE HELP AND CUSTOMS

In making a survey of the kind that was done in Kuwait, a number of native workmen must be employed. The Arab workers employed in Kuwait were willing, honest workmen. The standard of living in the country has been quite uniformly low with a consequence that there is practically no mechanization. Recently, some cars have come into the country, but there has been no transition from camel driving to car driving. The result is that the people have no mechanical background, but much of this lack of background is made up by willingness. The Arabs are natively intelligent, but one cannot expect a man who has never put a nut on a bolt to become a mechanic overnight. The combination of willingness and mechanical naivete did produce a number of exasperating situations until one thought about the background of the people. As an example, a surveyor running levels would send his rodman out for a foresight and the rodman would keep right on going over the next hill. The reasoning was that the surveyor with his remarkable telescope should be able to see the rodman anyhow.

A tribute to the ability of these people to learn is that at the end of six months the crew operated with satisfactory efficiency. At the end of eight months, the party was turning out work at a rate that would test a good many crews in this country.

The absolute honesty of the people of Kuwait should be mentioned. The Sheikh of Kuwait has an excellent knowledge of what is going on in his country. If there is a suspicion that any one has stolen anything, howsoever small, the offender finds out immediately that honesty does pay. The result was that not only could you lose nothing, you also could throw away nothing. Workmen were exceptionally careful about tools, nothing was lost through carelessness.

All of the people of Kuwait are Mohammedans. There was no friction caused by religious differences. Instead of being fanatical as travel books might suggest, the people were tolerant of the Occidentals. After all, the party was introducing foreign customs into a country that had enjoyed its own customs for centuries. For the most part, the party observed all of the Mohammedan feast days to the exclusion of the Western holidays. Christmas was the exception.

Another outstanding trait of the people was their hospitality. Often the surveyors would come across a Bedouin who would wave them down to ask them to come to his tent for a cup of coffee. The fact that the coffee was vigorously boiled probably compensated for the doubtful origin and purity of the water.

The major difficulty encountered in the country was that of language. It was difficult for the Americans to learn more than a few Arabic words, but the Arab workmen learned a basic English rapidly. The Arabic language is extremely perplexing in its grammar, pronunciation, and vocabulary. An entirely strange alphabet makes the written language forbidding.

One operating difficulty involved survey stakes. There is no wood in the country and every bit is valuable. The Bedouins would find the stakes, apparently loose in the desert, and would pull them up. After a few hundred had disappeared, the Sheikh of Kuwait sent word among the Bedouins that the stakes should not be disturbed. The survey stake situation then improved.

The Arabs customarily dress in long, flowing robes that are dangerous around machines. There is some reluctance on their part to change to trousers or shorts on a safety basis as they are inclined to be complete fatalists.

The employees were entirely made up of "city men." The desert Arabs, the Bedouins, will not accept work. The inborn sense of direction attributed to Arabs in travel books does not exist for the city Arabs. They would get completely lost the minute they were out of sight of town. However, the Bedouins actually do know their way about the desert. They have every landmark named and can find their way from one place to any other.

In working in the desert, the health of the party is of prime importance. A doctor was available from the local American-supported mission. The Middle East is host to a number of diseases that are rare in this country. Trachoma is common among the Arabs, although foreigners seldom seem to get it. Dysentery is widespread. Leishmaniasis which causes troublesome ulcers on the extremities is transmitted by sand flies and is common. During certain seasons, there is an unbelievable number of flies that resemble the common housefly. One can drive twenty miles into the desert without seeing life of any kind, open his lunch, and have it covered with flies before he can get a bite into his mouth. These flies transmit amoebic dysentery. Standards of sanitation must be kept very strict around a camp. The ordinary elements of an American diet are lacking in Kuwait. Mutton, fish, rice, and dates are about the only plentiful articles in the bazaars. Other items must be imported. The change in diet from fresh to canned foods often affects men new to the country.

SUGGESTED IMPROVEMENTS

The experience gained in this survey would indicate that well screened trailers would be better living quarters than tents. They could be heated in winter and they could be made flyproof. In wet weather, trailers keep men off the ground after a hard day's work. The efficiency of a party depends so much on its morale and health that too much cannot be done in this direction. A man's morale is helped if, at the end of a day's work, he does not have to contend with cold, dust, flies, or rain. This is particularly true where a party is isolated for a number of months without much change of scene.

Another change that experience would indicate is that the automotive equipment should be all-wheel drive whether the units are four or six wheel units. The added mechanical difficulties will be more than compensated by the better transportation.

MOTION OF AN ELASTIC SPHERE IN AN ACOUSTIC WAVE FIELD IN FLUIDS

ALFRED WOLF*

ABSTRACT

The motion of an elastic sphere in an acoustic wave field in fluids is determined as function of the elastic constants of the sphere, its radius, and the frequency of the wave field. It is found that the motion differs but little from the motion of an infinitely rigid sphere when the wave length of transverse waves in the elastic sphere is at least as long as the circumference of the sphere. The coefficient of zero order scattering potential in the fluid is determined.

The measurement of acoustic wave motion in fluids or in solid media by means of instruments of the seismograph type requires a knowledge of the dynamical interaction between the medium and the container in which the instruments are placed.

The solution of this problem was given in a recent paper by the writer[1] for the case of a spherical container of infinite rigidity. The motion of a sphere of infinite rigidity in acoustic wave fields in fluids was discussed in Section 3 of that paper, and the case of an infinitely rigid sphere imbedded in an infinite elastic solid was treated in Section 4. It should be noted that, after publication of the paper, the results of Section 3 were found to have been available in the literature.[2]

The work mentioned above suffers from a certain deficiency, namely, the lack of consideration of the elastic properties of the sphere on the interaction with the wave field in the medium in which it is placed. The extension of the work to the case of a solid elastic sphere in an acoustic wave field in fluids is given in the present paper. The work is facilitated by the use of a number of developments and formulae of Section 4 of "Motion of an Infinitely Rigid Sphere, etc." which can be used almost without change, and to which reference will be made.

The notation to be employed conforms to that of Section 4 of the previous paper. In particular, the symbol u denotes elastic displacement, F is a tension component, and the subscripts R, T refer to radial

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[1] Wolf, Geophysics, 10, 1945, p. 91.

[2] Lamb Hydrodynamics, 5th ed., 1930, art. 298.

and tangenital components respectively. The mathematical formulae of Section 2 of the former article are also used; it may be noted that Eqs. (8a)–(8d) are valid for the functions $\bar{f}$, $\bar{g}$ introduced in the following.

The problem to be solved may be stated as follows: An elastic sphere of mass M and radius a is placed in a fluid in which plane longitudinal waves of frequency $\omega/2\pi$ are propagated in a direction chosen as the $+z$-axis of a rectangular coordinate system with its origin at the center of the sphere. The amplitude of the velocity of wave motion in the fluid will be denoted V, the amplitude of displacement of the center of the elastic sphere is U; hence the velocity of the center of the sphere is $j\omega U$, and it is desired to determine

$$j\omega U/V \qquad (j = \sqrt{-1}).$$

The following symbols are introduced

$$R^2 = x^2 + y^2 + z^2 \qquad s = z/R \qquad q = \sqrt{1 - s^2}$$
$$\bar{f}_n(\xi) = (1/2j)[f_n^*(\xi) - f_n(\xi)] \tag{1}$$

where f_n is defined in Section 2 of "Motion of a Rigid Sphere etc.," and f_n^* is its complex conjugate. Two more functions are introduced

$$\bar{g}_n(x) \equiv \bar{f}_n(x) \qquad e_n(x) \equiv f_n(x). \tag{2}$$

The arguments of $\bar{f}_n$ will be ha or $\xi = hR$, the arguments of $\bar{g}_n$ are ka or $\eta = kR$, the arguments of e_n are ca or $\zeta = cR$, where

$h = 2\pi/$wave length of longitudinal waves in elastic sphere
$k = 2\pi/$wave length of transverse waves in elastic sphere
$c = 2\pi/$wave length of longitudinal waves in fluid.

$$h^2 = \delta\omega^2/(\lambda + 2\mu) \qquad k^2 = \delta\omega^2/\mu \tag{3}$$

λ, μ elastic constants (moduli) of the sphere
δ density of the sphere.

The functions $\bar{f}$, $\bar{g}$ are introduced because elastic displacements at the center of the sphere must remain finite, and, therefore, the solutions of the wave potential equations in the sphere must be written

$$\bar{f}_n(\xi) \cdot P_n(s) \qquad \bar{g}_n(\eta) \cdot P_n(s). \tag{4}$$

The first two orders may be written out explicitly

$$\bar{f}_0(x) = (\sin x)/x \qquad \bar{f}_1(x) = (x \cos x - \sin x)/x^2. \tag{5}$$

The corresponding e's are

$$e_0 = (1/\zeta)e^{-i\zeta} \qquad e_1 = -(j/\zeta + 1/\zeta^2)\cdot e^{-i\zeta}. \tag{5a}$$

The velocity potential in the fluid at a great distance from the sphere is

$$-(jV/c)e^{-jcz} \tag{6}$$

and its first order component can be written

$$(3jV/2c)[e_1(\zeta) - e_1^*(\zeta)]\cdot P_1(s).$$

As in "Motion of a Rigid Sphere etc.," only first order terms in developments in series of spherical harmonics need be considered since only first order terms of equations (41a) and (41b) of that article do not vanish at the center of the sphere. Hence, the potential in the fluid may be written

$$(3jV/2c)[e_1(\zeta) - e_1^*(\zeta)] + C_1 e_1(\zeta). \tag{7}$$

C_1 is the scattering coefficient of the first order which may be derived from boundary conditions; the factor $P_1(s)=s$ is omitted in Eq. (7) as well as in most of the following equations.

According to eqs. (41a) and (41b) of the previous paper, the two first order components of the elastic displacement in the sphere can be written

$$u_R = [A\bar{f}_1'(\xi) - 2B\bar{g}_1(\eta)/\eta]\cdot s. \tag{8a}$$

$$u_T = [A\bar{f}_1(\xi)/\xi + B(\bar{g}_1(\eta)/\eta + \bar{g}_0(\eta))]\cdot q. \tag{8b}$$

In the fluid, the velocity is given by

$$-\nabla\cdot\text{pot} \tag{9a}$$

and the pressure by

$$\delta p = j\omega\rho\cdot\text{pot} \tag{9b}$$

where ρ is the density of the fluid.

In the elastic sphere, the tension components are

$$F_R = \lambda\Delta + 2\mu\frac{\partial u_R}{\partial R} \quad \text{with} \quad \Delta = -hA\bar{f}_1(\xi)\cdot s \tag{10a}$$

$$F_T = \mu\left[\frac{q}{R}\frac{\partial u_R}{\partial s} + \frac{\partial u_T}{\partial R} - \frac{u_T}{R}\right]. \tag{10b}$$

The displacement of the center of the sphere U in the $+z$ direction is

$$U = (su_R + qu_T)_{R=0} = -(1/3)A + (2/3)B \tag{11}$$

because of

$$(1/\xi)\bar{f}_1(\xi) = -1/3 \quad f_0 = 1 \quad \bar{f}_1'(\xi) = -1/3 \text{ for } \xi = 0. \tag{12}$$

The boundary conditions require that

$$F_T = 0 \tag{13a}$$

$$F_R = -\delta p \tag{13b}$$

$$j\omega u_R = -\nabla[(3jV/2c)(e_1 - e_1^*) + C_1 e_1] \tag{13c}$$

at the surface of the sphere where $R = a$.

Equation (13a) determines the ratio B/A, and, in combination with Eq. (11), gives A and B in terms of U. Writing

$$D = \alpha + \beta/2 \tag{14a}$$

$$\alpha = 3\bar{f}_1(ha)/ha + \bar{f}_0(ha) \tag{14b}$$

$$\beta = 3\bar{g}_1(ka)/ka + \bar{g}_0(ka) - (1/2)ka\bar{g}_1(ka) \tag{14c}$$

it is easy to show

$$A = -(3/2)\beta U/D \qquad B = (3/2)\alpha U/D. \tag{15}$$

Substituting into Eq. (10a), and making use of Eq. (3)

$$\frac{aDF_R}{3U} = \frac{\delta\omega^2}{h^2} ah\bar{f}_1 \frac{\beta}{2} + \frac{\delta\omega^2}{k^2} ka\bar{g}_1\alpha \tag{16}$$

in which the arguments of $\bar{f}_1$, $\bar{g}_1$ are respectively ha and ka. Substituting Eq. (15) into Eq. (8a)

$$\frac{Du_R}{3U} = \frac{\alpha\beta}{2} - \left(\frac{\bar{g}_1}{ka}\alpha + \frac{\bar{f}_1}{ha}\frac{\beta}{2}\right) \tag{17}$$

at the surface of the elastic sphere.

Equations (16) and (17) can now be introduced into the boundary conditions (13b) and (13c), and the resulting equations may be solved for U, with the result

$$\frac{j\omega U}{V} = \frac{e^{jac}D}{(1/2)\alpha\beta(1 + jac) - 3GE}. \tag{18}$$

In this equation, which is the desired final result, α, β, D are defined by Eq. (14), and

$$G = \frac{\bar{f}_1}{ha}\,\frac{\beta}{2} + \frac{\bar{g}_1}{ka}\,\alpha$$

$$E = 1/3(1 + 2M/m)(1 + jac) - (1/3)(M/m)(ac)^2$$

where $M/m = \delta/\rho$ is the ratio of the mass of the sphere to the mass of the displaced fluid.

When the wave length is long enough to satisfy

$$ah \ll 1 \qquad ak \ll 1$$

the simplified result is obtained

$$\frac{j\omega U}{V} = \frac{e^{jac}}{\left[1 + \dfrac{a^2h^2k^2}{30k^2 - 40h^2}\right]E - \dfrac{a^2h^2k^2}{15k^2 - 20h^2}(1 + jac)} \cdot \tag{18a}$$

Finally, when Poisson's ratio for the material of the elastic sphere has the value 0.25, Eq. (18a) may be written

$$\frac{j\omega U}{V} = \frac{e^{jac}}{(1 + 0.06a^2h^2)E - 0.12a^2h^2(1 + jac)} \tag{18b}$$

which, of course, reduces to

$$j\omega U/V = e^{jac}/E \quad \text{as} \quad ah \to 0.$$

This is identical with the corresponding equation of the theory of an infinitely rigid sphere.

It is evident from Eq. (18a) and (18b) that the motion of an elastic sphere differs from the motion of an infinitely rigid sphere only by a negligible amount when the wave length of transverse waves in the elastic sphere is smaller than the circumference of the sphere. When the wave length of longitudinal waves in the elastic sphere is equal to the circumference, the motion differs from that of an infinitely rigid sphere only by an amount of the order of 10%.

In conclusion, the coefficient of the zero order, scattering potential in the fluid

$$C_0 e_0(\zeta)$$

may be given

$$C_0 = \frac{Ve^{jac}}{jc}\,\frac{(ac\cos ac - \sin ac)H - (m/M)\sin ac}{(1 + jac)H + m/M}$$

with

$$H = \frac{4}{k^2a^2} + \frac{1}{ah\cot ah - 1} \cdot$$

INTERPRETATION OF ISOSTATIC ANOMALIES SOUTH OF JAVA, USING INTEGRAL EQUATIONS AND CRUSTAL DEFORMATION THEORIES

C. W. HORTON*

ABSTRACT

The gravity measurements of Vening Meinesz show the existence of a symmetric belt of negative gravity anomalies south of Java. The mass distribution on a surface 40 kms deep which will explain the observed anomalies is determined by means of an integral equation. This mass distribution is interpreted as resulting from the deformation of a crust normally 40 kms thick. By applying Vening Meinesz's theory to the resulting deformation one concludes that the crust folded as though it had a Young's Modulus of 10^8 dynes/cm^2.

Some comments are made on Gunn's theory of mountain formation. It is shown that his theory predicts an increase in the compressive forces in the crust of 20 dynes/cm^2/year in the Paleozoic Era and of 80 dynes/cm^2/year in the Cenozoic Era. These values are shown to be in fair agreement with those predicted by the thermal contraction theory.

PART I: INTRODUCTION

The work of Vening Meinesz[1,2] has shown the existence of long narrow belts of large negative isostatic anomalies in the Dutch East Indies and in the West Indies. These negative "belts" or "troughs" have attracted much attention and many people have advanced theories to account for them. Of these might be mentioned Vening Meinesz,[2] Kuenen,[3] Griggs,[4] and Gunn.[5,6]

Figure 1 is a reproduction of a portion of the gravimetric map of the Dutch East Indies made by Vening Meinesz which shows the large negative belt south of Java.

* Underwater Sound Laboratory, Harvard University.

[1] Vening Meinesz, F. A., and Wright, F. E. *The Gravity Measuring Cruise of the U. S. Submarine S-21*, Pub. U. S. Naval Obs. 2nd ser. Vol. XIII, Appendix I. Washington, 1930.

[2] Vening Meinesz, F. A., *Gravity Expeditions at Sea*, Vol. II, Netherlands Geodetic Commission, Delft, 1934.

[3] Kuenen, P. H., *The Negative Isostatic Anomalies in the East Indies (with experiments)*, Leidsche Geo. Mededeelingen, Vol. 8, pp. 169–214, 1936.

[4] Griggs, David, *A Theory of Mountain-building*, Amer. Jour. Sci., Vol. 237, pp. 611–50, 1939.

[5] Gunn, Ross, *A Quantitative Study of Mountain Building on an Unsymmetrical Earth*, Jour. Frank. Inst., Vol. 224, pp. 19–53, 1937.

[6] Gunn, Ross, *A Quantitative Evaluation of the Influence of the Lithosphere on the Anomalies of Gravity*, Jour. Frank. Inst., Vol. 236, pp. 47–65, 1943.

Vening Meinesz found that the average anomaly for all of the gravity stations occupied in the Dutch East Indies was +19, +17, or +20 milligals, according to whether the values were reduced by the methods of Hayford and Bowie, Heiskanen, or Vening Meinesz respectively. The negative belts are much more local in occurrence than this positive anomaly which seems to spread over all of the Dutch East Indies, an area greater than nine million square kilometers. Therefore if one wishes to determine the local distribution of masses that produces the negative troughs, it seems very desirable to use +20 milligals as the reference level instead of zero.

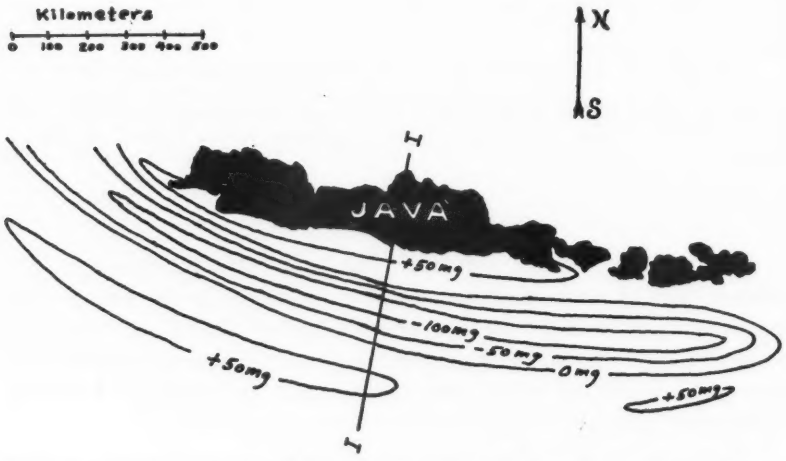

FIG. 1. Contour map of the Regional Isostatic Anomaly south of Java. Contou Interval 50 milligals. After Vening Meinesz.

The three types of anomalies, Hayford and Bowie, Heiskanen, and Vening Meinesz do not differ greatly, and for the trough south of Java, any one may be represented adequately by

$$A(x) = A_1(bx^2 - 1)e^{-x^2/a} \qquad (1)$$

where x is the distance from the center of the trough and A_1 is the anomaly at the center.

Equation (1) does not represent the data exactly but in view of the wide spacing of the observation points there does not seem to be sufficient justification for using a more complicated expression. For the cross-section *I–I* of Fig. 1, which is Profile 15 of Vening Meinesz's report, the parameters of Eq. (1) are found to be $A_1 = 130$ milligals,

and if x is measured in hundreds of kilometers, $a=2.0$ and $b=1$. Figure 2 shows a plot of Eq. (1), the Heiskanen anomaly and the Vening Meinesz anomaly for this cross-section.

In this analysis $A(x)$ will be interpreted as the Heiskanen anomaly resulting from a crust which is normally 40 kms thick and which rests on a substratum whose density is ρ c.g.s. units greater than that of the crust. In Vening Meinesz's work ρ is assumed to be 0.6 c.g.s. units but for the present the exact value is left unspecified. In order to form a concrete picture of the phenomenon, it will be assumed that initially there was a uniform crust 40 kms thick in the continental areas. Then

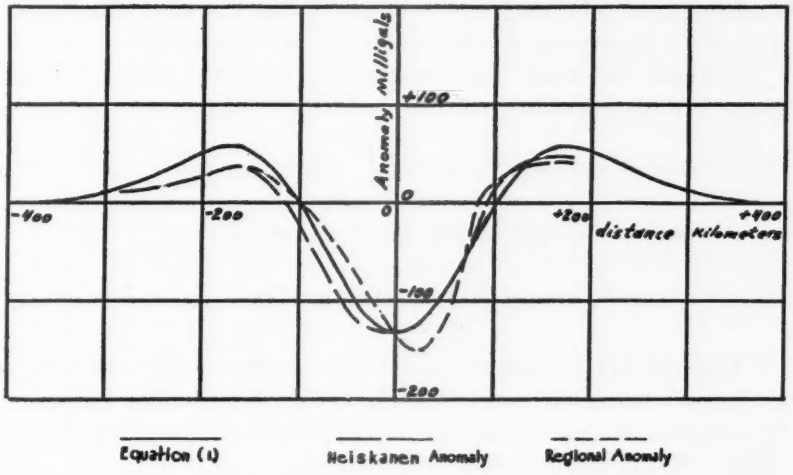

FIG. 2. Gravity profiles for the cross-section I-I of Fig. 1.
———— Equation (1).
—— —— Heiskanen anomaly
— — — — Regional anomaly

compressive horizontal forces displaced the crust from its equilibrium position. This displacement can give rise to surface features (including the ocean floor relief) which are uncompensated. Temporarily it will be assumed that all surface features are in isostatic equilibrium. If this assumption is true, the isostatic anomalies of Fig. 1 and Eq. (1) are largely due to the displacement of the bottom of the crust from its equilibrium position. As the displacements are small compared to the 40 kms to the bottom of the crust, the irregularities of the mass distribution can be represented by a surface distribution of mass at a depth of 40 kms. Since the belt is long and narrow, the problem may be treated as one of two-dimensions.

PART II: THE MATHEMATICAL SOLUTION OF THE PROBLEM

Consider rectangular coordinates x, y, z where the x- and y-axes are in the horizontal and the z-axis points vertically downward. Suppose that the plane $z=h$ has a surface distribution of mass $m(x)$ independent of the y-coordinate. Then the vertical component of the acceleration of gravity, $A(x)$ at a point $(x, 0, 0)$ is given by

$$A(x) = 2g \int_{-\infty}^{+\infty} m(u)hdu/\{(u-x)^2 + h^2\} \tag{2}$$

where g is the gravitational constant 6.67×10^{-8} c.g.s. units. This is an integral equation which may be solved for the mass distribution $m(u)$ when the gravity anomaly $A(x)$ has been observed.

Professor Bateman[7] has discussed the integral equation (2) and gives the following solutions:

$$m(x) = (1/2\pi^2 g) \int_0^{\infty} e^{hu}du \int_{-\infty}^{+\infty} A(\xi) \cos u(x-\xi)d\xi. \tag{3}$$

$$m(x) = (1/2\pi g)\{A(x+ih) + A(x-ih)\} - (1/2\pi^2 g) \int_{-\infty}^{+\infty} A(u)hdu/\{(u-x)^2 + h^2\}. \tag{4}$$

Equation (2) is of great importance in interpreting gravity data. In any region where the contours form straight parallel lines, a surface distribution of mass at any desired depth can be found from Eq. (4) which will explain the observed anomalies.

A few remarks concerning Eq. (4) may be made. If, for example, the observed gravity anomaly is a constant A_0, Eq. (4) becomes

$$m(x) = (1/2\pi g)(A_0 + A_0) - A_0/2\pi g = A_0/2\pi g \tag{5}$$

which agrees with the usual relationship for the gravity anomaly of a sheet of uniform mass density.

As another example suppose one asks what mass distribution will give a gravity anomaly of $A(x)=A_0 \cos(2\pi x/\lambda)$. If this function is inserted in Eq. (4) the integral can be evaluated by the method of residues to give

$$m(x) = (A_0/\pi g) \sinh(2\pi h/\lambda) \cos(2\pi x/\lambda) \tag{6}$$

[7] Bateman, H., *Some Integral Equations of Potential Theory.* Jour. App. Phys., Vol. 17, No. 2 (Feb. 1946), pp. 91–102. Equations (2), (3), and (4) of the present paper correspond to equations (6.1), (18.9), and (6.5) of Professor Bateman's paper.

As one would expect, the mass distribution that gives a cosine anomaly is itself a cosine distribution. The shorter the wave length of the anomaly, the greater is the necessary amplitude of the mass variation to account for the anomaly. Eq. (6) bears out the well known principle that if the gravity anomaly has narrow dimensions, then either the density contrast is very large or else the anomalous masses are very shallow.

Since the integral of Eq. (4) can not always be evaluated in a

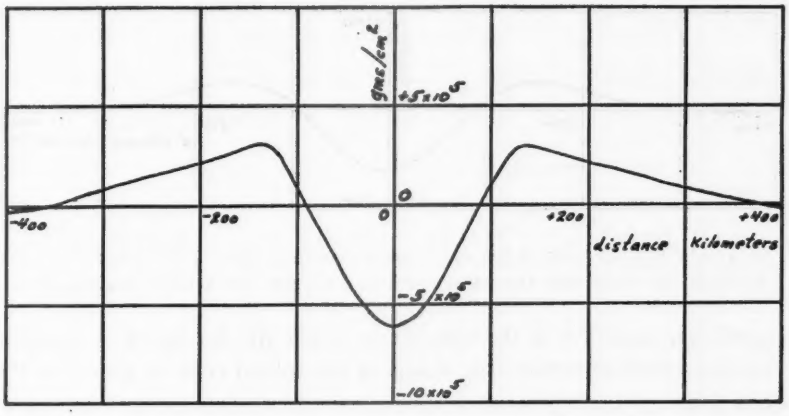

FIG. 3. The surface distribution of masses that explains the gravity anomaly of Equation (1).

closed form the following alternate form is given. If the gravity anomaly $A(x)$ has a Fourier transform $g(w)$ given by

$$g(w) = (1/\sqrt{2\pi}) \int_{-\infty}^{\infty} A(x) e^{-iwx} dx,$$

then the mass distribution can be written as

$$m(x) = (1/2\pi g)\{A(x + ih) + A(x - ih)\} - \{1/(2\pi)^{3/2} g\} \int_0^{\infty} \{g(w) e^{iw(x+ih)} + g(-w) e^{-iw(x-ih)}\} dw \quad (7)$$

PART III: APPLICATION OF THE MATHEMATICAL SOLUTION

Equation (1) fits the gravity data in the negative trough south of Java if $A_1 = 0.13$ gal. Substituting Eq. (1) in Eq. (4) and integrating one finds the mass distribution shown in Fig. 3. If the density contrast

between the crust and the substratum is 0.1 c.g.s. units, the shape of the bottom of the crust is that shown in Fig. 4 which has no vertical exaggeration. The folding will be greater or less according as the density contrast is smaller or larger respectively.

PART IV. VENING MEINESZ'S THEORY OF CRUSTAL DEFORMATION

Vening Meinesz[8] has developed the theory of the folding of the earth's crust for the case of large deformations. If x is the horizontal

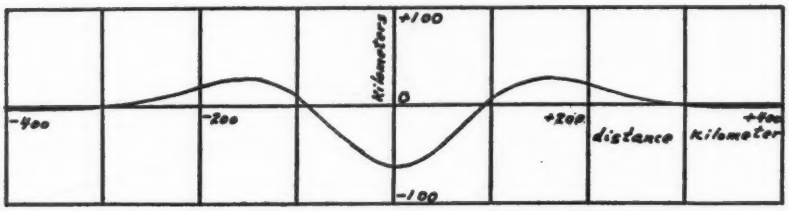

FIG. 4. The displacement of the earth's crust south of Java if the density contrast between the crust and the substratum is 0.1 c.g.s. No vertical exaggeration.

coordinate, and if y is the amplitude of the displacement, y being in the downward direction, the shape of the folded crust is given by the equations

$$\left.\begin{aligned} x &= 2c\,\mathrm{E}(\mathrm{am}\ l/c) - c\,\mathrm{F}(\mathrm{am}\ l/c) \\ y &= 2kc\,\mathrm{cn}(l/c) \end{aligned}\right\} \tag{8}$$

where cn u and am u denote two of the Jacobian elliptic functions: the cosine amplitude function and the delta amplitude function respectively of u,

F, E are the elliptic integrals of the first and second kinds of modulus k, which is also the modulus of the elliptic functions used,

$c = (ET^3/12(d_0 - d))^{1/4}$

E = Young's Modulus of the crust

T = thickness of the crust

d_0 = density of the displaced substratum

d = density of the replacing overlying material (air, water, or sediments)

l = the distance along the crust measured from the midpoint of the deformation.

[8] *Gravity Expeditions at Sea*, Vol. II, pp. 50–53.

Figure 5 is a reproduction of Fig. 16 of Vening Meinesz[9] which shows the shape of the displaced crust for several values of the modulus k.

Let us assume that the theory of Vening Meinesz is applicable to the crustal deformation that has been determined for the trough south of Java. Vening Meinesz shows that the value of k corresponding to Fig. 4 can be determined by the fact that when $y=0$,

$$\text{am}\,(l/c) = \pi/2$$

and

$$k = \sin\,(\theta_0/2)$$

where θ_0 is the angle between the deformed crust and the undeformed crust at the point where $y=0$. The first of Eqs. (8) can now be used to

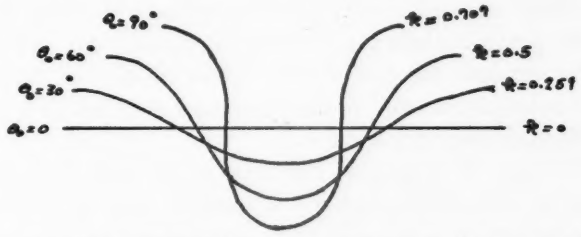

FIG. 5. Possible shapes of the displacement of the earth's crust according to the theory of Vening Meinesz.

determine c since the value of x for which $y=0$ is observed to be 90 kms. By using approximate values of T and (d_0-d) one can determine the values of the Young's Modulus E that governed the deformation in accordance with

$$E = 12(d_0 - d)c^4/T^3. \tag{9}$$

As remarked above, the actual shape of the crustal deformation depends on the magnitude of the density contrast ρ assumed between the crust and the underlying medium. Therefore the computation is presented in Table I for several values of ρ.

These values were computed for $T=40$ kms and $(d_0-d)=0.4$. (Note that ρ is the difference in density between the substratum and the crust; d_0-d is the difference in density between the substratum and the material (air, water, or sediments) filling the surface depression.)

[9] *Ibid.*, p. 51.

TABLE I. COMPUTATION OF YOUNG'S MODULUS FOR THE CRUST SOUTH OF JAVA

ρ	θ_0	k	2 E–F	c	E
				cms.	dynes/cm.^{2}
0.1	42° 5′	0.359	1.413	6.37×10^6	1.23×10^8
0.2	24°18′	0.211	1.517	5.93	0.93
0.3	16°46′	0.146	1.545	5.83	0.87
0.4	12°44′	0.111	1.556	5.78	0.84

Thus if in this instance the earth's crust deformed as an elastic plate, then during the process of deformation it behaved as though its Young's Modulus were 10^8 dynes/cm^2. This value is much smaller than any that has been observed experimentally.

PART V. THE EFFECT OF UNCOMPENSATED SURFACE FEATURES

It has been assumed above that the topographic features and the relief of the ocean bottom are in isostatic equilibrum. This need not be true. For example the compressive forces which fold the crust into the denser substratum can produce an ocean deep which will then be an uncompensated surface feature.

In computing the anomalies the direct effect of the uncompensated mass irregularities will be correctly allowed for but the assumption of isostatic equilibrium is equivalent to introducing an erroneous mass deficiency (or excess). Thus the curve of $m(x)$ in Fig. 3 should be more positive under regions where the topography constitutes a mass excess and more negative under regions where the ocean bottom shows a mass defect provided these irregularities are uncompensated. Thus a symmetric distribution of the gravity anomalies does not necessarily imply a symmetric displacement of the crust.

PART VI. THE GUNN THEORY OF MOUNTAIN FORMATION

The large negative belts of anomalies that have been observed lead Ross Gunn[10,11] to consider the problem of an elastic plate floating on a fluid or plastic substratum. This problem has been treated also by Goldstein,[12] Jeffreys,[13] and Vening Meinesz.[14] These investigations show that when sufficiently large horizontal forces are applied, the

[10] Ross Gunn, Jour. Frank. Inst., Vol. 224, pp. 19–53, 1937.
[11] Ross Gunn, Jour. Frank. Inst., Vol. 236, pp. 47–65, 1943.
[12] Goldstein, S. Proc. Camb. Phil. Soc., Vol. 23, pp. 120–129, 1926.
[13] Jeffreys, Harold. *The Earth.* 2nd Ed., pp. 287–288, 1929.
[14] *Ibid.*

crust will either be deformed into waves or will break according as its crushing strength is greater than or less than the critical value

$$S_c = \{(d_0 - d)gET/3\}^{1/2}. \qquad (10)$$

The symbols used here have the same meaning as in Part IV.

It might be mentioned that on page 28 of Gunn's paper d_0 is incorrectly defined as the density of the crustal material. This error has been repeated in a paper by Elkins[15] in which the formulae derived by Gunn are applied to the Appalachian structure.

Gunn assumes that "little error will be introduced if it is assumed that the crust will *not* flow plastically until 'one-sided' stress is applied to it which is of the order of the crushing strength of the rock." If typical values of E and T are substituted in Eq. (9) it is found that the critical value S_c is greater than the observed crushing strengths of crustal rocks. Therefore one concludes that if these values are typical, the crust will fault when the compressive forces become sufficiently great.

The conclusion that the crust will fault is not subscribed to by everyone. Griggs[16] has performed experiments in which pseudo-viscous flow was produced in Solenhafen Limestone under a confining pressure of 10,000 atmospheres. In this experiment the limestone was subjected to stresses in the neighborhood of 5×10^9 dynes/cm^2 which are larger than the crushing strength of the rocks at atmospheric pressure.

Further Kuenen[17] and Griggs[18] have separately constructed scale models which are dynamically similar to the earth's crust. These experiments indicate that a compressive force will produce a downfold of the crust or "tectogene" instead of a fault.

Gunn develops expressions for the displacement of the crust when faulting occurs. He obtains in a sample calculation an ocean deep 270 kms wide whose depth is 2.9 kms greater than that of the surrounding regions. The associated gravity anomaly reaches a minimum of -0.20 gal. Although some of the ocean deeps may be caused by crustal faulting the writer does not see any way of explaining a symmetrical isostatic anomaly profile with the mass displacements that could be produced by a thrust fault. This statement is true whether or not the surface features are compensated.

[15] Elkins, T. GEOPHYSICS, Vol. 7, pp. 45–60, 1942.
[16] Griggs, D. T. Jour. Geol., vol. 47, pp. 225–51, 1939.
[17] See reference 3.
[18] Griggs, D. T., Am. Jour. Sci., vol. 237, pp. 611–50, 1939.

It seems desirable to classify ocean deeps according as the gravity profile gives symmetric anomalies or not. The Nero deep east of Guam and the Mindanao deep are examples of deeps with unsymmetrical gravity profiles that may be associated with thrust faulting of the kind analyzed by Gunn.

Although the particular profile analyzed in Part III yields a distribution for the anomalous masses that suggests symmetric folding rather than faulting, it is probable that many synclines do develop along the evolution analyzed by Gunn. Elkins has found agreement at least in order of magnitude between field observations in the Alleghanies and the predictions of Gunn's theory.

One interesting check may be applied to Gunn's theory. He develops the following expression for the maximum thickness, D, of the synclinal wedge of sediments.

$$D = [3T(d_0 - d)g/E]^{1/4} S \sin 2\phi/(d_0 - d)g \qquad (11)$$

where T = thickness of the crust (50 kms)
g = acceleration of gravity (1,000 cm/sec^2)
E = Young's Modulus for the crustal material (10^{12} dynes/cm^2)
d_0 = density of the displaced substratum
d = density of the material (air, water, or sediments) that fills the geosyncline
ϕ = angle of the fault plane with the horizontal (30°)
S = magnitude of the horizontal compressive stress

The numerical values used are inclosed in parentheses.

If $d_0 - d$ is assumed to be 0.4, Eq. (10) becomes

$$D = S/1{,}500. \qquad (12)$$

Here D is measured in centimeters and S in dynes/cm^2. This relationship is derived on the assumption of static equilibrium. Actually the density, d, of the overlying material is changing with time because of sedimentation, etc. However the time variations are so small that the system may be safely assumed to be always in static equilibrium and so Eq. (12) may be considered as showing the dependence of the growth of the sedimentary column with the increase in the compressive forces. Hence

$$dD/dt = (1/1{,}500)dS/dt. \qquad (13)$$

Charles Schuchert[19] made a study of the rate of deposition of sedimentary strata and found that in the Paleozoic Era one foot of deposits was formed in 2,300 years while in the Cenozoic Era one foot accumulated in 580 years. Since he examined maximum thickness we may consider these figures to represent dD/dt.

TABLE II. COMPUTATION OF THE RATE OF INCREASE OF THE COMPRESSIVE FORCE

Era	dD/dt ft./yr.	dD/dt cm./yr.	dS/dt dynes/cm.^{2}/yr.
Cenozoic	1/580	0.0525	80
Paleozoic	1/2,300	0.0132	20

Table II shows the rate of increase of the compressive stress predicted by the Gunn theory. It is desirable to compare the values with those obtained from other sources. Jeffreys[20] concluded on the basis of the contraction that the earth's surface has contracted 5×10^{-3} ($=\Delta l/l$) in 1,500 millions of years. In one year this is $(5\times10^{-3})/(1.5\times10^{9})=3.3\times10^{-12}$. If the Young's Modulus is 10^{12} dynes/cm^2, this contraction corresponds to a change in the compressive force of 3.3 dynes/cm^2 per year. Although this value is six times smaller than the value obtained above for the Paleozoic Era, one hesitates to say that the two theories are incompatible when allowance is made for the uncertainties in the details of the two theories and for possible error in the value of the rate of sedimentation.

The discrepancy is greater by a factor of four in the Cenozoic Era but this can be attributed to a partial failure of the thermal contraction theory. E. M. Anderson[21] has shown that the heat loss necessary to explain the Tertiary mountains is five times the amount available.

The values of Table II may be tested in a different manner. Gutenberg[22] quotes a conclusion of Geszti that the formation of the Alps corresponds to a decrease of the Earth's radius of 2 kms. According to the results of Table II the shortening of the earth's radius is $(80\times\text{Radius})/10^{12}=3.7\times10^{-2}$ cm/year; and the time required to form the geosyncline that gave rise to the Alps is 5 millions of years. Ac-

[19] Charles Schuchert. *The Age of the Earth.* Bull. Nat. Res. Council No. 80 (1931).

[20] Jeffreys, Harold. *The Earth*, p. 285, Cambridge Press, 1929.

[21] Anderson, E. M. Gerlandes Beiträge zur Geophysik, Vol. 42, pp. 133–159, 1934.

[22] Gutenberg, B. The Internal Constitution of the Earth, p. 190, The McGraw-Hill Book Co., 1939.

tually the time would be greater since other mountains were being formed concurrently.

A value of 10^{12} dynes/cm^2 is used for Young's Modulus in this section since we are concerned with thrust faulting. It is necessary to use a large value to insure that the crust can transmit the large stresses necessary to produce faulting. The value of Young's Modulus of 10^8 dynes/cm^2 that is derived in Part IV is assumed to be typical only of the zones of weakness where the folding occurs.

ESTIMATING DEPTH AND EXCESS-MASS OF POINT-SOURCES AND HORIZONTAL LINE-SOURCES IN GRAVITY PROSPECTING

ERVAND GEORGE KOGBETLIANTZ†

ABSTRACT

The problem of the exact quantitative determination of the depth p and total excess-mass M of a point- and a line-source is solved with the aid of moments of the mapped gravity anomaly g_m, the correction for the regional anomaly being supposed as already applied. The solution does not presuppose that the constant error E in the regional datum is zero and this error is deduced from the gravity map itself. The relative errors which may affect the given estimates of p, M, E are studied and the magnitude of their upper limits is estimated in the case of a point-source only since the same analysis can easily be extended to the case of a line-source. The recommended method of solution reduces the harmful influence of extraneous anomalies from shallow mass points.[1] The details of mathematical proofs are given in an appendix.

INTRODUCTION

The problem of estimating the total excess-mass was studied in 1937 by Karl Jung[2] with the aid of the "Störungs-Integral."

$$(2\pi k)^{-1} \cdot \int_P \int g(x, y)dS = M \qquad (k = 66.7 \times 10^{-9} \text{ cgs.}) \qquad (1)$$

deduced from the Gauss' Theorem. In (1) the integration is to be carried over the whole infinite plane P of the map. The solution obtained by Jung is an unsatisfactory one since it presupposes a perfect correction for regional anomaly and disregards the error in the regional datum which is always present. But it is important as a first application of the Gauss Integral to our problem. A recent article by Hammer[3] raises an important question of the precision of excess-mass estimates with the aid of the integral (1) and his contribution to this point of

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[1] See E. Kogbetliantz. *Quantitative Interpretation of Magnetic and Gravitational Anomalies*. Geophysics, Vol. 9, No. 4, October 1944.

[2] K. Jung. *Directe Methoden zur Bestimmung von Störungsmassen aus Anomalien der Schwereintensität*. Zeitschrift fur Geophysik, Jahrgang 13, Heft 2/3, 1937 p. 46.

[3] S. Hammer, *Estimating ore masses in gravity prospecting*. Geophysics, vol. 10, No. 1, January 1945.

view is very interesting. The chief obstacle to the solution of the problem is the accurate correction for the regional anomaly and the first thing to do is to eliminate the constant error E (base-error) in the regional datum. We consider here three different methods of solution, comparing their relative value. We would recommend the third method as the best in our opinion.

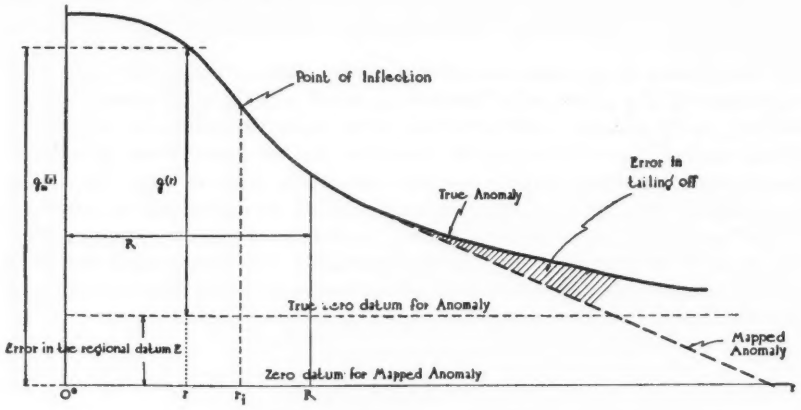

FIG. 1. Average radial gravity profile illustrating the quantities used in the formulation of the problem.

POINT-SOURCE

For a point-source the gravity anomaly is a function of the radius vector r only, that is $g_m = g_m(r)$, but in practice the contours differ from concentric circles and the radial profiles depend on the azimuth, θ. The best method to connect the mapped gravity values $g_m(r, \theta)$ characterizing these isogams with the values of the radius vector r, the origin O of polar coordinates (r, θ) being chosen vertically above the point-source,[4] consists in the evaluation of the area S for each contour with the aid of a planimeter and in ascribing to $g_m = g_m(r)$ of this contour the value of the square root $(S/\pi)^{1/2}$ as the corresponding value of the radius vector r. If an angular sector $\theta_1 \leqq \theta \leqq \theta_2$ of central angle $2a = \theta_2 - \theta_1$ is manifestly perturbed by some other adjacent anomaly, it can be excluded and the formula for r to be used in such a case becomes $r = [S_a/(\pi - a)]^{1/2}$, where S_a denotes the area of the contour

[4] The important point O is easy to locate with the aid of moments of g_m. See E. Kogbetliantz. *Quantitative Interpretation of Maps of Magnetic and Gravitational Anomalies by Mathematical Methods*. Quarterly of Applied Mathematics, vol. III, No. 1, April 1945, p. 63, Eq. 20.

minus the area of the perturbed sector. By this procedure we transform the map into an average radial profile for $g_m = g_m(r)$ known in a certain range of variation $(0, L)$ of the variable r.

1. *Inflexion-point Method.* The position of the inflexion-point at $r = r_i$ does not depend on the error E and the first method we study is based on the use of the value of gravity at the inflexion point, denoted by g_{mi}, together with its abcissa r_i. We must distinguish between the true value $g(r)$ of the anomaly and its mapped value $g_m(r)$, so that for a point-source we have

$$g_m(r) = g(r) + E = kMp(p^2 + r^2)^{-3/2} + E \qquad (2)$$

where E is the difference between the true and the mapped zero datum (see Fig. 1).

Solving the equation $g'(r) = 0$, we have $r_i = p/2$ and therefore, denoting the true value of gravity at the inflexion point by g_i, we have

$$g_i = g(r_i) = (8/5^{3/2})g_0 \qquad (3)$$

where $g_0 = g(0)$ is the maximum gravity at $r = 0$, namely, $g_0 = kM/p^2$.

Taking into consideration the difference E between the values of $g_m(r)$ and $g(r)$ and using the theoretical value $8/5^{3/2}$ of the ratio g_i/g_0, we obtain an equation for E since $g_i = g_{mi} - E$, $g_0 = g_{m0} - E$, the quantities g_{mi} and g_{m0} being the mapped values of gravity at the inflexion-point and at the maximum respectively on our average radial profile $g_m = g_m(r)$. This equation solved for E gives

$$E = g_{mi} - 8(g_{m0} - g_{mi})/(5^{3/2} - 8) \qquad (4)$$

or approximately $E = 3.5g_{mi} - 2.5g_{m0}$. The depth p is simply $p = 2r_i$. For M we use now the integral of the product $r \cdot g_m(r)$. Integrating it over $(0, R)$, where R is less than L but otherwise arbitrary, we obtain from Eq. 2

$$\int_0^R g_m(r) r dr = kM\{1 - [1 + (R/p)^2]^{-1/2}\} + ER^2/2 \qquad (5)$$

and the left hand member is easy to compute as area under the curve of $rg_m(r)$ in the interval $(0, R)$. Now $p = 2r_i$ and, substituting in Eq. 5 the expression for E in Eq. 4, and using the abbreviation $x = (1 + R^2/4r_i^2)^{1/2}$, we deduce from Eq. 5 the following estimate of M in cgs units:

$$kM = x\cdot(x-1)^{-1}\left\{\int_0^R [g_m(r) - g_{mi}]rdr + 4R^2(g_{m0} - g_{mi})/(5^{3/2} - 8)\right\}, \quad (6)$$

where k is the gravitational constant and the number x depends on the choice of R. The estimate of M by Eq. 6 does not depend on the base-error E. Another form of this equation is

$$M = 0.75R^2x(x-1)^{-1}\left\{2R^{-2}\int_0^R g_m(r)rdr - (5^{3/2}\cdot g_{mi} - 8g_{m0})/(5^{3/2} - 8)\right\}, \quad (6^*)$$

where the excess-mass M, the gravity $g_m(r)$ and the length R are expressed in metric tons, hundredths of milligal and meters respectively. A slight improvement would be the replacement of the integral over $(0, R)$ by the double integral

$$I_R = \iint_{r\leq R} g_m(r, \theta)dS$$

which can be deduced directly from the original map by evaluating the areas $S(g)$ of contours g_m=constant, plotting the curve of the area S as a function $S=S(g)$ of g and computing I_R with the aid of a planimeter as an area bounded by the S-axis and the curve $S=S(g)$, since in general

$$\int_0^R \phi(r)rdr = \iint_{r\leq R} \phi(r)dS/(2\pi).$$

The chief source of error in the mass estimates by Eqs. 6 or 6* is in the incorrect choice of the inflexion point $r=r_i$. The precision with which M is evaluated in Eq. 6 depends on the value of the coefficient of proportionality $f(x)$ in the relation

$$dM/M = f(x)\cdot dr_i/r_i \quad (7)$$

between the two relative errors dM/M and dr_i/r_i. Computing $f(x)$, we find:*

* See appendix A.

$$f(x) = (x+1)x^{-2} + 2.4x(x+1)/(5^{3/2} - 8). \tag{8}$$

The result (8) is important. The function $f(x)$ is expressed in terms of the auxiliary variable $x=(1+R^2/4r_i^2)^{1/2}$ to facilitate the study of its behavior when R varies. It is easy to show that $f(x)$ is decreasing for $R=0$(i.e. $x=1$) because $f'(1)\cong -3/4$, passes through a minimum for $R=0.87r_i(x=1.09)$ and increases with R for $R>0.87r_i$. The best value which can be chosen for R, namely $R=0.87r_i$, does not assure a satisfactory estimate of M since the minimum of $f(x)$ is approximately equal to 3.46 and therefore we have, for all choices of R

$$|dM|/M \geqq 3.46\,|dr_i|/r_i.$$

Thus a small relative error in the location of the inflexion-point causes a large error in the estimate of M. Another defect of formula 6 is the use of the individual station values g_{m0} and g_{mi}. In the opinion of the writer, such a use of isolated station values is often a source of important errors and it must be avoided if possible.

2. *Mixed Method.* In the second approach to the solution of our problem let us consider the average values of gravity H_i and H_R in the circles $r\leqq r_i$ and $r\leqq R$ respectively, thus using only the position of the inflexion-point. They are

$$H_i = 2r_i^{-2}\int_0^{r_i} g_m(r)r\,dr = E + kMr_i^{-2}/(2.5+5^{1/2}) \tag{9_1}$$

$$H_R = 2R^{-2}\int_0^{R} g_m(r)r\,dr = E + 2kM/[R^2+4r_i^2+2r_i(R^2+4r_i^2)^{1/2}]. \tag{9_2}$$

Using instead of g_{m0}, g_{mi} these averages H_i, H_R and eliminating M, we deduce the following equation for E

$$[R^2 + 4r_i^2 + 2r_i(R^2 + 4r_i^2)^{1/2}]\cdot(H_R - E) = 2(2.5 + 5^{1/2})r_i^2(H_i - E)$$

and its solution with the aid of an auxiliary angle ω defined by $R=2r_i\cdot\tan 2\omega$, $0<\omega<\pi/4$ takes the form:

$$E = \frac{4H_R\cos^2\omega - (2.5+5^{1/2})H_i\cos^2 2\omega}{4\cos^2\omega - (2.5+5^{1/2})\cos^2 2\omega}. \tag{10}$$

On the other hand, eliminating E, we obtain an estimate for M, namely:

$$4kM = [\sin^2\omega - \tan^2 2\omega/(2.5+5^{1/2})]^{-1}\cdot R^2(H_R - H_i). \tag{11}$$

To study the precision of this estimate we apply again the same procedure as for Eq. 6 observing that a variation dr_i of r_i causes a corresponding variation $dH_i \neq 0$ of H_i, but $dH_R = 0$ since H_R does not depend on r_i.

Using the abbreviation Cos $2\omega = z$, we have*

$$dM/M = q(z)dr_i/r_i = [z^2 + Az + B + AC^2 \cdot (z + C)^{-1}] \cdot dr_i/r_i \quad (12)$$

with $A = 5 - 8/5^{1/2} = 1.422 \cdots$; $B = 16(2.3 - 5^{1/2}) = 1.024 \cdots$ and $C = 2(5^{1/2} - 2) = 0.472 \cdots$. The range of variation for $z = \text{Cos } 2\omega = 2r_i/(R^2 + 4r_i^2)^{1/2}$ considered as a function of R is from 0 to 1 and z is a decreasing function of R. Therefore, the functions $q(z)$ and $q'(z)$ both being positive or zero in the interval $0 < z \leqq 1$, the coefficient $q(z)$ in Eq. 12 is also a decreasing function of R, which means that the *precision of the mass estimate by Eq. 11 increases when R becomes larger.* For $R = 0$, that is $z = 1$, we have $q(1) = 3.66$ and the minimum of $q(z)$ corresponding to $R \to \infty$ is $q(0) = 1.695$. Thus

$$3.66 \left| dr_i \right| / r_i \geqq \left| dM \right| / M \geqq 1.7 \cdot \left| dr_i \right| / r_i$$

and we see that the mass estimate by Eq. 11 is much better than the estimate by Eq. 6. The relative error dr_i/r_i often exceeds 10%, as the inflexion point is in general difficult to locate exactly. It is plain that the relative error of the estimate by Eq. 11 can easily reach 30%, as for instance, if we choose $R = 2r_i (z = 2^{-1/2})$ we have $q(2^{-1/2}) = 2.85$. We need therefore a more precise estimate and we find it in the Moments' Method.

3. *Moments' Method.* We define the nth moment of mapped gravity $g_m(r)$ in the interval (O, R) by the following integral

$$m_n = \int_0^R g_m(r) \cdot r^n dr$$

so that the product $R^{1-n} \cdot m_n$ has the dimension of a volume. Our aim is to deduce the estimates of E, p, M in terms of moments m_n. These estimates depend in general on the value of R used and, choosing different values of R, one can check the solutions obtained with the aid of moments. The estimates of E, p, M in terms of moments belong in fact to a family of solutions with the parameter R. The range of variation for R is the interval (O, L), where L is the length of the known radial profile.

Using many different values of R we obtain as many different

* See appendix B.

numerical estimates for each of our three parameters E, p, M. If their dispersion is too great we must conclude that our point-source hypothesis does not work, the real shape of the anomalous mass being too far from spherical. On the contrary, if the different values obtained for the same parameter do not diverge, their average can be interpreted as the best value which can be ascribed to this parameter as a result of quantitative interpretation. Using Eq. 2 in the definition of m_n, we find

$$m_n = R^{n+1}E/(n+1) + kMp \cdot \int_0^R (p^2 + r^2)^{-3/2} \cdot r^n dr.$$

Evaluating the integral and introducing, instead of the depth p, the auxiliary unknown $c = p/R$, we have

$$R^{1-n} \cdot m_n = R^2 \cdot E/(n+1) + kM \cdot f_n(c)$$

where

$$f_n(c) = c^{n-1} \cdot \int_0^{1/c} (1 + t^2)^{-3/2} \cdot t^n \cdot dt.$$

Thus

$$f_0(c) = [c \cdot (1 + c^2)^{1/2}]^{-1}; \qquad f_1(c) = 1 - c \cdot (1 + c^2)^{-1/2}$$

and

$$f_2(c) = c \cdot \{\ln [c^{-1} + (1 + c^{-2})^{1/2}] - (1 + c^2)^{-1/2}\}.$$

We can tabulate any $f_n(c)$ since for $n \geqq 2$ we can use the recurrence formula

$$(n-1) \cdot f_{n+1}(c) = c \cdot [(1 + c^2)^{-1/2} - nc \cdot f_{n-1}(c)] \qquad (n \geqq 2).$$

Any three moments of different orders can be used to form a system of three equations in three unknowns c, E, M. Combining for instance three consecutive moments m_{n-1}, m_n, $m_{n+1} (n \geqq 1)$, we obtain for c the following equation:

$$F_n(c) = A_n \cdot [nf_{n-1}(c) - (n+2)f_{n+1}(c)] - B_n[nf_{n-1}(c) - (n+1)f_n(c)] = 0$$

with $A_n = (n+1) \cdot Rm_n - n \cdot R^2 \cdot m_{n-1}$, $B_n = (n+2)m_{n+1} - nR^2 m_{n-1}$. For a fixed and known n the equation $F_n(c) = 0$ can be solved since the numbers A_n, B_n can be computed, using the anomaly map, and all the functions $f_n(c)$ are known. Having found c, we have the following expressions of M and E in terms of moments and $f_n(c)$:

$$kM = B_n R^{-n} \cdot [(n+2) f_{n+1}(c) - n f_{n-1}(c)]^{-1}$$

$$E = \frac{n(n+2) R^{-n} [m_{n-1} \cdot f_{n+1}(c) - R^{-2} \cdot m_{n+1} \cdot f_{n-1}(c)]}{(n+2) \cdot f_{n+1}(c) - n f_{n-1}(c)}.$$

Taking for instance $n=1$, we have for c the equation

$$F(c) = \{1 + 3c^2 - 3c^2(1+c^2)^{1/2} \cdot \ln [c^{-1} + (1+c^{-2})^{1/2}]\} [(1+c^2)^{1/2} + c]^2 = j$$

where $j=(R^2 m_0 - 3m_2)/(2Rm_1 - R^2 m_0)$. Tabulating $F(c)$ we can find c which corresponds to the value j of $F(c)$. This function $F(c)$ varies too slowly to permit satisfactory evaluation of the value of c, but other combinations of moments give more sensitive equations. We propose to use the moments m_0, m_1 and m_3. The quantities Rm_0, m_1 and $R^{-2}m_3$ can be deduced from the radial profile of $g_m(r)$ by evaluating the areas below the curves $g_m(r)$, $r g_m(r)$ and $r^3 \cdot g_m(r)$ respectively from $r=0$ to R. On the other hand we must have

$$Rm_0 = R^2 E + kM \cdot [c(1+c^2)^{1/2}]^{-1}$$

$$m_1 = R^2 E/2 + kM \cdot [(1+c^2)^{1/2} - c] \cdot (1+c^2)^{-1/2}$$

$$2R^{-2}m_3 = R^2 E/2 + 2kMc \cdot [(1+c^2)^{1/2} - c]^2 \cdot (1+c^2)^{-1/2}$$

and we can form the combinations $A = Rm_0 - 4m_1 + 4R^{-2}m_3$, $B = Rm_0 - 2m_1$ and $C = m_1 - 2R^{-2} \cdot m_3$ which do not depend on E, namely

$$\begin{aligned} A &= kM \cdot [(1+c^2)^{1/2} - c]^4 \cdot [c \cdot (1+c^2)^{1/2}]^{-1} \\ B &= kM \cdot [(1+c^2)^{1/2} - c]^2 \cdot [c \cdot (1+c^2)^{1/2}]^{-1} \\ C &= kM \cdot [(1+c^2)^{1/2} - c]^3 \cdot (1+c^2)^{-1/2}. \end{aligned} \tag{13}$$

Using Eq. 13, we express c and $2kM$ in terms of A, B and $C=(B-A)/2$:

$$c = C \cdot (AB)^{-1/2} \tag{14}$$

$$2kM = (A+B) \cdot BC \cdot A^{-2}. \tag{15}$$

Forming the combination $R^{-1} \cdot m_0 \cdot m_3 - m_1^2 = D$, we obtain the following formula for estimating the value of the base-error E

$$E = 4R^{-2} \cdot D \cdot A^{-1}. \tag{16}$$

The important parameter c, which is given by Eq. 14, may be expressed as the solution of the equation

$$Z(c) = c \cdot [(1+c^2)^{1/2} - c] = C/B = N, \tag{17}$$

where the function $Z(c)$ varies between 0 and 0.5 when c increases from zero to infinity:

$c\rightarrow$	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1	2	5
$10^3Z(c)\rightarrow$	0	91	164	223	271	309	339	364	384	399	414	472	495

which shows that $z(c)$ varies rapidly for $c=0$ to 1, but very slowly for $c>1$. Therefore the value of c as given by Eqs. 14 or 17 cannot be found with great accuracy for $c>1$ the variation of N being too slow. Recalling that $c=p/R$, we see that this method will not give an accurate determination of the value of c for small values of R. The solution (14) for c is equivalent to

$$c = N\cdot(1 - 2N)^{-1/2}.$$

In practice a geophysicist often has to deal with the interpretation of short profiles and for this case we propose another method which yields a very accurate determination of the depth $p=cR$. Computing first E with the aid of Eq. 16 the mapped anomaly can be corrected by eliminating the error E in the regional datum, and then c is found as follows. If $E=0$ we form for each r, $0<r<R$, the ratio $y(r)=g(r)/g(u)$, where $u=u(R, r)=(R^2-r^2)^{1/2}$ and plot the curve of an auxiliary function of r, $Q(r)$, defined by

$$Q(r) = [y(r)]^{4/3} + 2[y(r)]^{2/3} - 3.$$

It is easy to verify that for a point-source the expression of $Q(r)$ as a function of r is simply

$$Q(r) = [(R^2 + 2p^2)/(r^2 + p^2)]^2 - 4$$

and thus

$$2R^{-2}\int_0^R Q(r)rdr = c^{-2}(1 + c^2)^{-1} = T(c). \qquad (18)$$

Tabulating the function T of c, we find that Eq. 18 is much more sensitive for large values of c, i.e. small values of R, than Eq. 17

$10c\rightarrow$	0	1	2	3	4	5	6	7	8	9	10	20	50
$T\rightarrow$	∞	99	24	10.2	5.4	3.2	2.04	1.37	0.91	0.68	0.5	.05	.0015

Given the value T of the integral in the left hand member of Eq. 18, the corresponding value of c can be computed by the rule

$$c^2 = 2\cdot[T + (T^2 + 4T)^{1/2}]^{-1}. \qquad (19)$$

Errors in the estimates given by eqs. 14, 15 and 16 can be caused by accidental errors $\delta g(r)$ in the values of $g_m(r)$ in the interval (0, R). Since a constant error in $g_m(r)$ is a part of E we can assume that the mean accidental error is zero:

$$\int_0^R \delta g(r) \cdot dr = 0,$$

but the mean of the square $[\delta g(r)]^2$ is positive and we define σ by

$$R \cdot \sigma^2 = \int_0^R [\delta g(r)]^2 dr$$

as the mean quadratic accidental error in (0, R). As an approximate measure of the accidental errors affecting $g_m(r)$ in the interval (0, R) we choose a number e defined by

$$e = \left\{ R \int_0^R [\delta g(r)]^2 dr \right\}^{1/2} \Big/ \int_0^R g(r) dr$$

$$= R^2 \cdot \sigma \cdot c(1 + c^2)^{1/2} / kM = (1 + c^{-2})^{1/2} \cdot \sigma / g(0). \qquad (20)$$

We now have to compare with e the upper limits for the relative errors $\delta c/c$, $\delta E/E$, $\delta M/M$ of our estimates caused by the deviations $\delta g(r)$. In practice e is very small and does not exceed 0.01. A study of the upper limits for $\delta A/A$, $\delta B/B$, $\delta C/C$ with the aid of the Schwarz Inequality proves* that in the range $0.1 < c < 0.5$, that is, $2p < R < 10p$ (which seems to be the most convenient since it corresponds to smaller values of relative errors) we have

$$|\delta c| / c < 5e \quad \text{and} \quad |\delta M| / M < 11e. \qquad (21)$$

The right hand members in inequalities 21 are the greatly exaggerated upper limits of the relative errors and for these upper limits we have 5% and 11% respectively, if $e = 0.01$. The value of e depends on many factors and in particular on the choice of R. Formula 20 shows that the value of e is a product

$$e = [\sigma/(\max g)] \cdot [(1 + c^{-2})]^{1/2}, \qquad (c = p/R)$$

whose first factor is very small, for anomalies which are not too weak, if the smoothing of the contours was performed carefully. The second factor, $(1+c^{-2})^{1/2}$, diminishes if R decreases and this circumstance is

* See appendix C.

favorable as it allows the use of short intervals (o, R). The results given by Eqs. 21 presuppose a point-source as the cause of the anomaly and they do not hold if this hypothesis is not justified.

We add that the same rules hold for the interpretation of a magnetic vertical anomaly created by an infinite vertical circular cylinder (magnetic plug) of small radius a with its top at the depth $p=cR$, if the magnetization is also vertical. In fact, in this case the vertical component of the anomaly $Z_m(r)$ is expressed by

$$Z_m(r) = Z(r) + E = \pi a^2 \cdot Ip(p^2 + r^2)^{-3/2} + E,$$

where I and E are the intensity of magnetization and the base-error respectively, $\pi a^2 I$ replacing kM.

LINE-SOURCE

For an infinite horizontal line-source at a depth $p=cR$ we have, taking as x-axis a profile perpendicular to the line-source:

$$g_m(x) = g(x) + E = 2kMp(p^2 + x^2)^{-1} + E, \qquad (22)$$

where k is the gravitational constant and M is the excess-mass per unit of length. The origin, o*, is determined (at a position which is vertically above the line source) with the aid of the formula[5]

$$x^* = \overline{oo^*} = \int_{-\infty}^{\infty} x' g(x') dx' \Big/ \int_{-\infty}^{\infty} g(x') dx',$$

the origin, o, of coordinate x' being any point of the profile. Taking o* as the origin of coordinate, we compute the moments of gravity m_n in the interval $(-R, R)$

$$m_n = R^{-n} \cdot \int_{-R}^{R} g_m(x) \cdot |x|^n \, dx,$$

using the known profile of $g_m = g_m(x)$. On the other hand their theoretical values can be obtained from Eq. 22

$$m_n = 4kMf_n(c) + 2R \cdot E \cdot (n+1)^{-1}, \qquad (23)$$

where $f_0(c) = \arctan(1/c)$, $f_1(c) = c \cdot \ln[(1+c^{-2})^{1/2}]$ and, for $n \geqq 1$,

$$f_{n+1}(c) = n^{-1} \cdot c - c^2 f_{n-1}(c).$$

The base-error E is found with the aid of the first five moments:

[5] See Reference 1, p. 470, Eq. 9.

$$RE = 30 \cdot \begin{vmatrix} m_0 & m_2 & 6 \\ m_1 & m_3 & 3 \\ m_2 & m_4 & 2 \end{vmatrix} / (16m_1 - 15m_2 - 3m_0). \qquad (24)$$

The depth p can be obtained from many different solutions for the unknown $c=p/R$. Taking, for instance, any four non-negative integers n, q, s, t we can form and tabulate the function $F(c)$ defined by

$$F(c) = [(n+1)f_n(c) - (q+1)f_q(c)][(s+1)f_s(c) - (t+1)f_t(c)]^{-1}.$$

On the other hand a number $N=N(n, q, s, t)$ can be computed using the experimental curve $g_m=g_m(x)$, if it is defined with the aid of moments. Defining N by

$$N = [(n+1)m_n - (q+1)m_q][(s+1)m_s - (t+1)m_t]^{-1},$$

we have the equation $F(c)=N$. Solving it we obtain a value for c. Different choices of the integers n, q, s, t as well as of the integration interval $(-R, R)$ provide control on the values of c obtained. Two examples of ratio $F(c)$ follow: The function $F_1(c)$ defined by choosing $s=0$, $t=1$, $n=2$, $q=3$, that is $F_1(c)=(3m_2-4m_3)/(m_0-2m_1)$, is equal to: $F_1(c)=c\{[1-c\cdot\arctan(1/c)].[\arctan(1/c)-c\cdot ln(1+c^{-2})]^{-1}-2c\}$. This function varies from zero to 0.4 when c increases from zero to infinity. The second ratio $F_2(c)$ corresponds to the choice $s=0$, $t=2$, $n=2$, $q=4$:

$$F_2(c) = 3c\cdot[4 + 15c^2 - 3c(3+5c^2)f_0(c)][(1+3c^2)f_0(c) - 3c]^{-1}.$$

The variation of $F_2(c)$ is much more complicated than that of $F_1(c)$ and $F_2(c)$ changes its sign four times when c ranges from zero to infinity. The equation $F_2(c)=N_2$ has five positive roots if $N_2<1.06$ and therefore the second ratio can be used only as an auxiliary tool which enables us to find a more precise value of c for which the first approximate value has already been found with the aid of the equation $F_1(c)=N_1$. Tabulating these two ratios in the interval $0\leqq c\leqq 2$, we have:

$10c$	0	1	2	3	4	5	6	7	8	9	10	12.5	15	20
$10^3F_1(c)$	0	65	120	169	206	237	262	282	300	314	326	346	361	379
$10^2F_2(c)$	0	23	42	57	69	79	88	95	100	105	106			

Among many possible combinations of moments which give practical rules for finding c and which hold for $E\neq 0$ we cite here only the estimate

$$c^2 = (15m_4 - 16m_3 + 3m_2)/(16m_1 - 3m_0 - 15m_2). \qquad (25)$$

After having found c with the aid of (25) we can estimate E, using one of two following expressions

$$RE = 3 \cdot [(2m_1 - m_0) \cdot c^2 + 2m_3 - m_2]$$
$$RE = 5 \cdot [(3m_2 - 2m_1)c^2 + 3m_4 - 2m_3],$$

and also kM with the aid of

$$4kM = (3m_2 - m_0) \cdot [3c - (1 + 3c^2) \cdot \arctan (1/c)]^{-1}.$$

The estimate of E by Eq. 24 allows us to eliminate the base-error and after its elimination we can use the very sensitive rule (19) to estimate the depth factor c, where the dimensionless number T is defined and computed with the aid of the ratio $r(x) = g(x)/g[(R^2 - x^2)^{1/2}]$:

$$T = R^{-2} \cdot \int_{-R}^{R} [3 + r(x)] \cdot [r(x) - 1] \cdot |x| \, dx. \qquad (26)$$

It is easy to check that $T = c^{-2} \cdot (1 + c^2)^{-1}$ since $g(x)$ is proportional to $(p^2 + x^2)^{-1}$ and $c = p/R$. The number T can be evaluated from the experimental data also by using the integrals of the square $g^2(x)$ and of its reciprocal $g^{-2}(x)$:

$$T = 3 \cdot \left\{ R^{-4} \cdot \int_{-R}^{R} g^{-2}(x) \cdot |x| \cdot dx \cdot \int_{-R}^{R} g^2(x) \cdot |x| \, dx - 1 \right\}. \qquad (27)$$

Knowing c, it is easy to find the excess-mass per unit of length M. We have, for instance,

$$4kM = (m_0 - 2m_1)/[\arctan (1/c) - c \cdot \ln (1 + c^{-2})] \qquad (28)$$

where k is the gravitational constant.

CONCLUSION

We observe that the determination of the depth and position of the centroid of the anomalous mass, with the aid of which we have deduced the estimates of the excess-mass, constitutes in itself a very powerful tool in the hands of an experienced geophysicist in general.

Under the important hypothesis of a constant density contrast the location of the centroid of the finite anomalous mass can be determined not only for a point- or line-source but for any solid of revolution in a three-dimensional problem and for any configuration of finite

disturbing masses in a two-dimensional problem. In the general case of a three-dimensional problem our methods can locate only the point o*, the projection of the centroid of the anomalous mass on the map plane. For any assumed geometrical form of disturbing masses with variable density contrast it is possible to find the location of the centroid only if the law of variation of density contrast is known. Nothing can be said about this location if the variation of density contrast through the disturbing masses is unknown.

APPENDIX A

An error dr_i in the location of the inflection point causes a corresponding error dg_{mi} in g_{mi} and, denoting by G_i the gradient of gravity at $r=r_i$:

$$dg_{mi} = G_i \cdot dr_i = [-0.96 \cdot g_0 / r^{1/2}] \cdot (dr_i/r_i),$$

$g_0 = kMp^{-2}$ being the true value of the maximum. Therefore, since $R = 2r_i(x^2-1)^{1/2}$

$$-R^2 \cdot dg_{mi}/kM = 0.96(x^2-1)5^{-1/2} \cdot dr_i/r_i. \qquad (29)$$

Differentiating Eq. 6 with respect to x and g_{mi} as dependent variables of r_i, we obtain

$$-dM/M = dx/x(x-1) + 5^{3/2}R^2 \cdot x \cdot dg_{mi} \cdot [2(5^{3/2}-8)(x-1)kM]^{-1}.$$

But $-dx = (x^2-1)x^{-1}dr_i/r_i$ and, using Eq. 29, we prove (8).

APPENDIX B

Differentiating Eq. 9_1, where M is to be considered now as the result of the estimate by Eq. 11, we use $g_{mi} = g_i + E$; $5^{3/2} \cdot g_i = 2kMr_i^{-2}$ and obtain between dE, dM/M and dr_i/r_i the relation

$$dM/M = 0.4(2 + 5^{1/2})dr_i/r_i - (2.5 + 5^{1/2})r_i^2 dE/kM. \qquad (9_1^*)$$

On the other hand the differentiation of Eq. 9_2 gives

$$-(2.5 + 5^{1/2})r_i^2 dE/kM = -4(2.5 + 5^{1/2}) \cdot [r_i/(R^2 + 4r_i^2)^{1/2}]^3 \cdot (dr_i/r_i) + 2(2.5 + 5^{1/2})r_i^2 \cdot [R^2 + 4r_i^2 + 2r_i(R^2 + 4r_i^2)^{1/2}]^{-1} \cdot (dM/M). \qquad (9_2^*)$$

Using $2r_i = R$ Cotan 2ω and eliminating dE, we deduce from Eqs. 9_1^*, 9_2^*:

$$\{2 + 2z - (2.5 + 5^{1/2})z^2\}\,dM/M$$
$$= (2.5 + 5^{1/2})(1 + z)\cdot[(2/5^{1/2})^3 - z^3]dr_i/r_i,$$

where $z = \text{Cos } 2\omega = 2r_i/(R^2+4r_i^2)^{1/2}$ is simply an abbreviation. Dividing both sides by a common factor $2/5^{1/2}-z$, we prove Eq. 12.

APPENDIX C

We begin by studying $\delta A/A$, $\delta B/B$ and $\delta C/C$. It is plain that we can estimate only their greatly exaggerated upper limits since the only tool we can use is the so called Schwartz inequality

$$\left\{\int_a^b f(x)g(x)dx\right\}^2 \leqq \int_a^b f^2(x)dx\cdot\int_a^b g^2(x)dx.$$

Applied to $\delta A = \int_0^R (R - 4r + 4R^{-2}r^3)\delta g(r)dr$ and to similarly expressed δB, δC this inequality yields

$$|\delta A| \leqq 0.468R^2\cdot\sigma, \quad |\delta B| \leqq 0.577R^2\cdot\sigma, \quad |\delta C| \leqq 0.324R^2\cdot\sigma.$$

Equation 13, which gives values of A, B, C and Eq. 20, which gives $R^2\sigma/kM = e/[c(1+c^2)^{1/2}]$, yield now:

$$|\delta A|/A \leqq ae; \quad |\delta B|/B \leqq be; \quad |\delta C|/C \leqq he$$

where, using the abbreviation $S = c+(1+c^2)^{1/2}$,

$$a = 0.468\cdot S^4 \qquad b = 0.577\cdot S^2 \qquad h = 0.324\cdot S^3c^{-1}.$$

The minimum of the coefficient h corresponds to $c=0.35$ and it is equal to 2.5, a and b being equal to 1.8 and 1.1 respectively if $c=0.35$. When c decreases (with increasing R) a and b decrease, but h increases. So, for instance, for $c=0.2$ we have $h=2.94$, $a=1$, $b=0.86$. In practice we cannot often choose a great R and therefore it is important to observe that for $c=0.5$ we have $a=3.2$, $b=1.5$, $h=2.7$. The range $0.1<c<0.5$ (i.e., $2p<R<10p$) seems to be the most convenient since it corresponds to smaller values of relative errors. For this range we find as upper limit for $|\delta c|/c$

$$|\delta c|/c \leqq |\delta C/C + 0.5(|\delta A|/A + |\delta B|/B) < 5e$$

which is equivalent to the result that the relative error in the determination of the depth p by (14) or (17) cannot exceed 5%, since e does not, in general, exceed 0.01. This result presupposes a point source as cause of the anomaly and in practice it does not hold if this hypothesis is not justified.

For the determination of M by Eq. 15 the precision is less satisfactory:

$$\delta M/M=\delta B/B-2\delta A/A+\delta(B-A)/(B-A)+\delta(B+A)/(B+A),$$

where $B-A=2kMS^{-3}(1+c^2)^{-1/2}$ and $B+A=2kMS^{-3}c^{-1}$. Computing the upper limits for $\delta(B\pm A)$, we find

$$|\delta(B-A)|/(B-A)\leqq 0.332S^3c^{-1}\varepsilon;$$
$$|\delta(B+A)|/(B+A)\leqq 0.415S^3(1+c^2)^{-1/2}\cdot\varepsilon$$

and therefore for $0.1<c<0.5$ we have proved Eq. 21.

PATENTS*

ELECTRICAL PROSPECTING

U. S. No. 2,390,270. R. G. Piety. Iss. 12/4/45. App. 1/5/42. Assign. Phillips Petroleum Co.

Method of Surface Prospecting. A four electrode a-c method of electrical prospecting in which one current electrode and one potential electrode are far apart and the other two electrodes are on a perpendicular line between them, the phase and magnitude of potentials being measured to a number of stations on the line for each current electrode station on the line.

GEOCHEMICAL PROSPECTING

U. S. No. 2,386,832. W. M. Zaikowsky and H. E. Metcalf. Iss. 10/16/45. App. 8/20/40. Assign. Consolidated Engineering Corp.

Method of Obtaining Soil Gas Samples. A method of soil gas sampling in situ by inserting a hollow cylindrical cutter which isolates the interior portion of the soil, heating by an electrical heater on the inside wall of the cutter or by passing steam through the sample, and collecting released gas through a central perforated pipe.

U. S. No. 2,389,706. P. S. Williams and M. W. Kriegel. Iss. 11/27/45. App. 1/7/43. Assign. Standard Oil Development Co.

Apparatus for Gas Analysis. A portable soil gas analysis system having a combination of scrubbers, triple trap, U tube, pump, mercury reservoir and Pirani gauge, combustion of the sample being accomplished by a high voltage discharge through the triple trap at reduced pressure.

GRAVIMETRIC PROSPECTING

U. S. No. 2,387,489. L. H. Bailey. Iss. 10/23/45. App. 6/14/45. Assign. Gulf Research & Development Co.

Jolly Balance. A Jolly balance for measuring specific gravity of rocks by water immersion of a sample and which is made direct reading by having a movable variable-scale chart.

U. S. No. 2,389,866. M. E. Moore. Iss. 11/27/45. App. 6/10/39. Assign. Sun Oil Co.

Apparatus for Making Gravity Measurements. A gravity meter having a quartz beam suspended horizontally from one end by the torque from twisting through 90° the plane of two spaced quartz fibres under tension.

MAGNETIC PROSPECTING

U. S. No. 2,374,166. L. F. Beach and J. C. Purves. Iss. 4/24/45. App. 8/2/41. Assign. The Purves Corp.

Magnetic Field Responsive Device. A flux gate magnetometer having four coils which are connected as a Wheatstone bridge circuit and whose cores are arranged as a magnetic bridge circuit.

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation Patent Department.

U. S. No. 2,389,146. C. F. Fragola, M. C. Depp, and R. S. Curry, Jr. Iss. 11/20/45. App. 1/19/43. Assign. Sperry Gyroscope Co.

Flux Valve. A flux valve type transmitter for a remote indicating magnetic compass or repeater system and having a toroidal shaped core excited by a single phase winding and having multiphase pick-up windings.

U. S. Re. 22,699 (Orig. No. 2,361,433). A. A. Stuart, Jr. Iss. 11/27/45. App. 5/21/40, 10/31/42 and 10/31/44. Assign. Bendix Aviation Corp.

Magnetic Compass. A flux valve type compass transmitter with Autosyn repeater, the transmitter having an inner toroidal core excited by single phase a-c and having three pole pieces 120° apart carrying pick-up coils.

U. S. No. 2,390,051. G. Barth. Iss. 12/4/45. App. 7/15/41. Vested in Alien Property Custodian.

Means for Measuring Magnetic Fields. A flux gate magnetometer in which the cores are alternately magnetized in opposite directions by the use of rectifiers or synchronous vibrator and the differential current indicated.

SEISMOGRAPH PROSPECTING

U. S. No. 2,387,223. H. Carson. Iss. 10/16/43. App. 2/6/43. Assign. Research Corp.

Vibration Pickup. A suspended magnet dynamic type vibration pickup using oil damping and in which long period is obtained by using two split suspension rings mechanically in series.

U. S. No. 2,387,701. T. Dove, Jr. Iss. 10/23/45. App. 1/27/43. Assign. American Cyanamid & Chemical Corp.

Lowering Device for Large Cartridges. A device for lowering dynamite cartridges into shot holes consisting of a rod which may be pushed down the axis of the cartridge and having an expendable wood pin through the lower end to support the cartridge and an eye for a rope at the upper end.

U. S. No. 2,387,770. S. D. Rogers, P. J. Rudolph and W. L. Crawford. Iss. 10/30/45. App. 12/16/41. Assign. Olive S. Petty.

Spray Deflector for Shot Holes. A spray deflecting shield for the top of a cased shot hole and curving over the hole like a cowl and hinged so that it may be swung out of the way when loading the hole.

U. S. No. 2,388,232. C. O. Tappan. Iss. 10/30/45. App. 5/8/41. Assign. Kirby H. Tappan.

Stemming Device for Explosive Charges. A blasting plug having a central tapered mandrel surrounded by segments to form a cylindrical plug which is expanded to grip against the sides of the hole by the force of the explosion.

U. S. No. 2,388,703. R. A. Peterson. Iss. 11/13/45. App. 9/20/41. Assign. United Geophysical Co., Inc.

Geological Prospecting System. A refraction method of seismic prospecting for ore bodies by observing relative travel times and plotting ray directions to the geophones and locating the ore from the convergence characteristics of the ray lines.

U. S. No. 2,389,086. J. Stuart, II. Iss. 11/13/45. App. 1/30/42.

Electric Detonator. A waterproof electric blasting cap having a hard resinous plug which carries the leg wires and bridge wire and is pressed into the shell tight enough to bulge the shell slightly.

U. S. No. 2,390,187. J. A. Sharpe. Iss. 12/4/45. App. 10/22/41. Assign. Stanolind Oil and Gas Co.

Seismic Surveying. A system of seismic surveying in which a channel records the conventional compressional reflected wave and another channel records the rotational effect of the transverse reflected wave by means of a detector sensitive to rotation only, the time difference between the waves being used to identify the formation above the interface.

U. S. No. 2,390,322. J. O. Parr, Jr. Iss. 12/4/45. App. 9/19/41. Assign. Olive S. Petty.

Seismic Surveying. An avc system for seismograph amplifiers which has a normal avc to change grid bias of amplifier tubes and also has a supplemental avc normally below cut-off which operates to change grid bias of tubes when excessively large signals are received.

U. S. No. 2,390,328. R. J. Roberts. Iss. 12/4/45. App. 6/25/43. Assign. Standard Oil Development Co.

Directional Seismograph Pickup. A suspended magnet variable air gap reluctance type geophone which has several sets of coils and pole pieces facing in different directions and recording independently.

WELL LOGGING AND SURVEYING

U. S. No. 2,385,857. G. Herzog. Iss. 10/2/45. App. 1/29/44. Assign. The Texas Co.

Cushioning Device for Radiation Detectors. A radioactivity logging detector surrounded by a resilient protector which prevents jars from disturbing the electrodes and causing spurious indications when the instrument is run at high speed.

U. S. No. 2,386,514. J. C. Stokes. Iss. 10/9/45. App. 6/11/42. Assign. Reed Roller Bit Co.

Side Hole Coring Device. A side wall coring device having an undersize rotary core cutter on a drill stem and carrying a floating whipstock which may be set hydraulically and which deflects the core cutter into the wall formation.

U. S. No. 2,387,513. C. R. Hocott. Iss. 10/23/45. App. 8/8/41. Assign. Standard Oil Development Co.

Well Logging. A method of geochemical well logging in which samples are added to an electrolytic half cell which is sensitive to a small amount of a reducing component and the change in potential correlated with depth.

U. S. No. 2,388,141. G. G. Harrington. Iss. 10/30/45. App. 1/4/43. Assign. Reed Roller Bit Co.

Electrical Logging Apparatus. A device for electrical logging without removing the drill stem and which has a motor operated hammer in the drill collar, the motor current being supplied by a battery and flowing through the formation via two electrodes so that the frequency of hammer blows as determined acoustically at the surface indicates the formation impedance.

U. S. No. 2,388,896. C. B. Aiken. Iss. 11/13/45. App. 1/28/42. Assign. Schlumberger Well Surveying Corp.

Electrical Method and Apparatus for Logging Boreholes. A method of accentuating the spontaneous potential indication of porous formations by using apparatus having two electrodes with flexible circular insulators between them to form a horizontal electrical barrier in the hole.

U. S. No. 2,389,208. W. P. Orr. Iss. 11/20/45. App. 1/22/43. Assign. Standard Oil Development Co.

Side Wall Sample Taking Apparatus. A wire line operated side wall sampler which may be dropped through a core bit and latched to the drill stem and having a core cutter forced against the wall by a spring and into the formation by weight of the drill stem.

U. S. No. 2,389,241. D. Silverman. Iss. 11/20/45. App. 4/26/44. Assign. Stanolind Oil and Gas Co.

Well Logging. Apparatus for signalling from the drill bit to the surface for logging or vice versa for control operations and having a transformer in the drill collar, the high side being connected to the electrode system in the well and the low side being connected between an auxiliary electrode and the drill stem, so that ground return current to the latter may be detected at the surface.

U. S. No. 2,389,512. G. A. Humason. Iss. 11/20/45. App. 1/28/43.

Tester for Wells. A formation tester having a flexible probe and which may be lowered through the drill stem and guided into the formation at various angles by a guide in the lower end of the drill stem.

U. S. No. 2,390,178. H. M. Rutherford. Iss. 12/4/45. App. 6/21/41.

Drilling Rate Recorder. A drilling time recorder in which a pen is moved across the recording tape by a clock, a new line being started across the tape for each unit of depth drilled.

U. S. No. 2,390,409. C. B. Aiken. Iss. 12/4/45. App. 2/4/42. Assign. Schlumberger Well Surveying Corp.

Electrical Logging. A two electrode a-c well logging apparatus in which high and low frequencies are simultaneously applied to an impedance bridge having the two electrodes in one arm, the bridge output being filtered to separate the frequencies, rectified and transmitted to the surface.

U. S. No. 2,390,433. R. E. Fearon. Iss. 12/4/45. App. 3/25/40 and 7/29/44. Assign. Well Surveys, Inc.

Well Survey Method and Apparatus. A neutron well logging method using a neutron source and two ionization chambers with different shielding and in which the scattered neutrons are detected by one ionization chamber and secondary gamma radiation simultaneously detected by the second ionization chamber.

U. S. No. 2,390,931. R. E. Fearon. Iss. 12/11/45. App. 1/6/41. Assign. Well Surveys, Inc.

Well Logging Method. A method of well logging in which there is dissolved in the drilling fluid an artificially radioactivated sodium compound and the amount of solution absorbed in the formations determined by a radioactivity log.

U. S. No. 2,390,965. S. A. Scherbatskoy. Iss. 12/11/45. App. 4/20/44. Assign. Well Surveys, Inc.

Central Electrode Support. A resilient central electrode support for the ionization chamber of a well logging instrument, the electrode being made of telescoping tubing extended by a spring and the lower end of the electrode having an insulating section which fits into a conical socket.

U. S. No. 2,391,093. L. G. Howell. Iss. 12/18/45. App. 8/12/38. Assign. Standard Oil Development Co.

Radioactivity Well Logging. A gamma ray well logging method and apparatus using an ionization chamber whose current is indicated at the surface or using two Geiger counters whose discharge rates are independently indicated at the surface by frequency meters.

MISCELLANEOUS

U. S. No. 2,386,089. L. J. Bobb. Iss. 10/2/45. App. 3/31/44. Assign. Philco Radio and Television Corp.

Phonograph Pickup Device. A moving coil dynamic type phonograph pickup for lateral cut records in which the stylus mounting yields to endwise motion caused by the pinch-effect without actuating the coil.

U. S. No. 2,386,643. C. F. Wallace. Iss. 10/9/45. App. 9/14/44. Assign. Wallace & Tiernan Products, Inc.

Precise Level Determination Apparatus. A device for determining the top of a liquid column in a manometer tube and having a magnet floating on the liquid and an external slider with a pivoted magnetic vane and pointer which detects the position of the magnet.

U. S. No. 2,386,692. W. E. Kuenstler. Iss. 10/9/45. App. 4/5/44.

Crystal. A mounting for a piezo-electric crystal in which the crystal with its electrodes and leads are all embedded in a molded plastic.

U. S. No. 2,386,777. W. W. Bentley, Jr. Iss. 10/16/45. App. 4/8/42.

Accelerometer. A vertical accelerometer having a closed tube mercury manometer, the height of mercury being detected by change in resistance of a wire running down the inside of the manometer tube or by a series of contacts sealed into the tube.

U. S. No. 2,386,830. N. Wright. Iss. 10/16/45. App. 9/2/42. Assign. The Dow Chemical Co.

Method and Apparatus for Continuous Analysis and Control of Organic Systems. A method of analysis or process control in which light from an infra-red source is passed through the sample to be analyzed and into two thermocouple cells having different absorption bands and whose difference in thermal emf is indicated.

U. S. No. 2,386,831. N. Wright. Iss. 10/16/45. App. 9/2/42. Assign. The Dow Chemical Co.

Method and Apparatus for Continuous Analysis of Organic Mixtures While in Motion and for Control of Systems Comprising Such Mixtures. A method of analysis or process control in which two beams from an infra-red source are passed into two thermocouple cells having different absorption characteristics and whose difference in thermal emf is indicated, the sample to be analyzed being interposed in one of the beams.

U. S. No. 2,386,879. R. H. Ostergren. Iss. 10/16/45. App. 9/17/43. Assign. Douglas Aircraft Co., Inc.

Strain Gauge and Method of Producing It. A filament type strain gauge in which the leads to the filament are cemented to the backing at the junctions and have an adjacent unbonded flexed portion which may give so as to relieve the junction of strain.

U. S. No. 2,387,496. J. R. Cornelius. Iss. 10/23/45. App. 9/22/43 and 3/21/44.

Method and Means for Making Fine Measurements. An ultramicrometer in which the beat frequency acts on two tuned circuits one of which is tuned higher and one lower than normal beat frequency and the difference in their rectified responses indicated.

U. S. No. 2,387,550. L. T. Winkler. Iss. 10/23/45. App. 10/16/41 and 11/23/42.

Electrical Method of and Apparatus for the Analysis or Identification of Gases, Vapors and the Like. A method and apparatus for analysis based on ion mobility measurements and in which fortuitous ions are first removed and the gas then ionized and ions collected at a series of electrodes.

U. S. No. 2,387,737. E. A. Black. Iss. 10/30/45. App. 1/10/45.

Tensiometer. A cable tensiometer having two spaced clamps around the cable and a pair of flexed spring strips between them, the flexure of the strips decreasing with cable elongation.

U. S. No. 2,387,786. H. W. Washburn. Iss. 10/30/45. App. 7/20/42. Assign. Consolidated Engineering Corp.

Analytical System. A method of admitting a gas sample to the ionization chamber of a mass spectrometer by passing the gas through orifices under pressure conditions such that flow of each component is independent of the others in order to obtain linear superposition of ion intensities.

U. S. No. 2,387,832. J. R. Cooney. Iss. 10/30/45. App. 4/18/44.

Reproduction of Sound. An arrangement for removing background noise from a snake type sound track by allowing part of the transmitted light to fall on an auxiliary photocell whose signal is fed into the modulated photocell to correct for light intensity variations.

U. S. No. 2,387,845. W. R. Harry. Iss. 10/30/45. App. 6/24/43. Assign. Bell Telephone Laboratories, Inc.

Electroacoustic Transducer. A directional condenser microphone in which stabilized inverse feedback is obtained by applying the amplifier output to the diaphragm and auxiliary electrode.

U. S. No. 2,388,105. J. A. Wilson. Iss. 10/30/45. App. 12/9/43. Assign. Standard Oil Development Co.

Spectrograph. A continuously recording spectrograph in which the wave length changing screw has a switch which at definite wave lengths connects the amplifier circuit to a condenser so as to record a transient mark on the chart as known wave lengths are passed.

U. S. No. 2,388,303. H. M. Wise. Iss. 11/6/45. App. 1/30/43.

Elastic Measuring Scale. A scale made on elastic material fastened between the arms of an expanding holder so that by squeezing the holder the scale length may be varied.

U. S. No. 2,388,387. T. A. Cohen. Iss. 11/6/45. App. 2/26/43. Assign. Wheelco Instruments Co.

System for Measuring the Time Interval for Moving Bodies to Traverse Predetermined Distances. A timer for a dropping ball viscosity meter in which the ball falls a measured distance between two condenser plates, the change in capacity tuning an oscillator so that change in its plate current will operate a relay controlled timer.

U. S. No. 2,388,542. W. V. Hobbs. Iss. 11/6/45. App. 5/15/44. Assign. Ranco Inc.

Pressure Measuring Device. A bellows type pressure gauge having a gas chamber with expanding bellows and in which the length of the bellows is maintained constant by a contact which controls an electric heater, the equilibrium temperature of the gas being measured.

U. S. No. 2,388,671. N. Brewer. Iss. 11/13/45. App. 5/26/43. Assign. Fischer & Porter Co.

Flow Responsive Switch. A signalling switch for insertion in a flow line and having a rotameter type flow meter whose float makes electrical contacts when flow is too high or too low.

U. S. No. 2,388,672. N. Brewer. Iss. 11/13/45. App. 8/13/43. Assign. Fischer & Porter Co.

Flow Measuring Device. A rotameter type flow meter which has a flanged metering tube for mounting in a pipe flange and a metering float having a stem extending into an adjacent sight tube.

U. S. No. 2,388,683. R. E. Frickey and C. W. McKee. Iss. 11/13/45. App. 3/26/41. Assign. Welding Service, Inc.

Method and Apparatus for Detecting Flaws in Rails. A car mounted rail testing unit with which magnetic homogeneity of the rail is observed on a c-r tube screen, the car being stopped and the unit moved manually for detailed examination and marking of an observed flaw.

U. S. No. 2,388,727. E. C. Dench. Iss. 11/13/45. App. 5/29/42. Assign. Interchemical Corp.

Glossmeter. A system for comparing the reflection qualities of small flat samples by rapidly turning them over in a light beam and picking up reflected light with a photocell

connected to a cathode ray oscilloscope whose sweep is synchronized with the turning motor.

U. S. No. 2,388,848. W. C. Howe. Iss. 11/13/45. App. 11/2/40. Assign. Maguire Industries, Inc.

Magnetic Shielding for Transformers and the Like. Magnetic shielding having nesting shells formed of sheet bent into a cylindrical shape and with end caps which lap the sheet and having separators between shells.

U. S. No. 2,388,966. V. S. Harrison. Iss. 11/13/45. App. 5/13/44. Assign. Consolidated Vultee Aircraft Corp.

Electrical Strain Gauge. A filament type strain gauge in which the filament is wound over a grooved core and plates on each side deform the wire into the grooves when strain is applied.

U. S. No. 2,389,046. D. G. C. Hare. Iss. 11/13/45. App. 9/4/41. Assign. The Texas Co.

Method of Analyzing Gases. A method of determining oxygen content of a gas by admixing nitric oxide and measuring the reduction in light transmission.

U. S. No. 2,389,081. L. B. Redmond. Iss. 11/13/45. App. 9/14/43. Assign. Socony-Vacuum Oil Co., Inc.

Galvanometer. A multiple element moving coil permanent magnet fluid damped galvanometer unit in which each element housing has pole pieces which fit into slots in the magnet unit.

U. S. No. 2,389,190. G. F. Fermier. Iss. 11/20/45. App. 11/27/42. Assign. Reed Roller Bit Co.

Testing Means. A method of testing surface properties of magnetic materials by subjecting them to an alternating flux and varying the depth of flux penetration by changing the frequency, a coil applied to the material being energized by an oscillator whose frequency is changed by a motor driven switch which synchronously switches the abscissa of a c-r oscillograph spot whose ordinate is proportional to coil impedance.

U. S. No. 2,389,432. C. W. Hansell. Iss. 11/20/45. App. 6/24/42. Assign. Radio Corp. of America.

Communication System by Pulses Through the Earth. A ground communication method in which very short current pulses are applied to two electrodes at high frequency and the spacing or relative timing of successive pulses varied in accordance with signals.

U. S. No. 2,389,603. L. L. Dollinger. Iss. 11/27/45. App. 2/1/44. Assign. Dollinger Corp.

Flow Indicator. A deflected vane type rate of flow meter having a bent vane which presents an effective area to the flow stream which is independent of deflection.

U. S. No. 2,389,615. J. P. Eder. Iss. 11/27/45. App. 10/9/43.

Anemometer. A hot wire fluid flow meter in which the heated element is in one arm of a bridge circuit and having compensation for ambient temperature changes and a range changing circuit.

U. S. No. 2,389,649. R. E. Stark and D. E. Stark. Iss. 11/27/45. App. 6/15/42. Assign. Stupakoff Ceramic & Manufacturing Co.

Variable Intensity Light Signalling Apparatus. A modulated infra-red light beam signalling apparatus in which the light source is a refractory glower made of a conductor of the second class.

U. S. No. 2,389,828. L. M. Swift. Iss. 11/27/45. App. 2/24/42. Assign. Engineering Laboratories, Inc.

Recorder. A multichannel recorder having a series of galvanometers the position of whose reflected light beam is detected by a photocell which periodically scans the beams and marks the beam deflection on a chart by a relay controlled marker.

U. S. No. 2,389,935. J. Rothstein. Iss. 11/27/45. App. 6/24/43.

Microphonic Electron Tube. An electron tube having a flexible bellows sealed into the envelope and the grid mechanically connected to a diaphragm at the outer end of the bellows.

U. S. No. 2,389,957. C. E. Cox. Iss. 11/27/45. App. 9/13/43.

Flowmeter. A multi-range flowmeter of the tapered vertical tube and float type in which tubes having different flow capacities are connected in series.

U. S. No. 2,390,038. A. C. Ruge. Iss. 11/27/45. App. 9/12/44. Assign. The Baldwin Locomotive Works.

Temperature Compensated Gauge. A filament type strain gauge having an intermediate lead wire between the filament and the main leads, the intermediate leads being made of material whose temperature coefficient of resistance compensates the effect of temperature changes on the gauge.

U. S. No. 2,390,252. J. T. Hayward. Iss. 12/4/45. App. 12/29/41.

Apparatus for Determining Permeabilities of Porous Media. An apparatus for comparing permeabilities of core samples and using a Wheatstone bridge type of flow system and in which the calibrated variable permeance is a tube having a slightly tapered central plunger which changes the annular flow space when moved in or out of the tube.

U. S. No. 2,390,304. H. Hitchen. Iss. 12/4/45. App. 6/18/43 and 8/23/44. Assign. British Ropes Ltd.

Means for Determining and Recording the Stresses in Wire Ropes, Chains, etc. A link to be mounted in a line to record stress and having a mechanical strain gauge operating a stylus which records on a moving celluloid strip.

U. S. No. 2,390,383. J. Neufeld. Iss. 12/4/45. App. 6/16/42.

Navigational Method and Apparatus. A device for automatically obtaining a true bearing from a radio bearing and a compass bearing by using two perpendicular direction finding loops, obtaining a d-c voltage proportional to their signal ratio and adding in series a voltage proportional to the compass indication.

U. S. No. 2,390,739. S. A. Scherbatskoy. Iss. 12/11/45. App. 10/15/42.

System and Apparatus for Measuring Cloud Height and Thickness. A device which

may be dropped from a plane and having a radio transmitter which is modulated by a photoelectric turbidity meter and by contact with the ground, the cloud thickness and ceiling being determined by timing the signals received during fall.

U. S. No. 2,390,783. H. C. Drake. Iss. 12/11/45. App. 12/23/41. Assign. Sperry Products, Inc.

Rail Flaw Detector Mechanism. A device for short-circuiting the input to a rail flaw detector when passing over joints and having fingers which contact the joint bar and operate a relay.

U. S. No. 2,391,627. A. S. Howell. Iss. 12/25/45. App. 1/19/44. Assign. Stromberg-Carlson Co.

Transducer. A self-energized telephone of the magnetic reluctance type in which one end of the magnetic reed is stationary and the other end is fastened to the diaphragm.

U. S. No. 2,391,633. A. Korn, J. W. Hess, and S. L. Ruskin. Iss. 12/25/45. App. 5/25/43.

Automatically Operated Object Locating System. A system for locating an object from two stations by means of supersonic waves whose reflection time from the object is reported to the other station by radio and the object location plotted by a telautograph at each station.

U. S. No. 2,391,678. F. P. Bundy. Iss. 12/25/45. App. 8/29/45. Assign. U. S. A.

Magnetostriction Transducer. A magnetostriction electroacoustic transducer in which a polarizing magnetic flux is produced by a permanent magnet across one end of a U-shaped core.

DISCUSSIONS AND COMMUNICATIONS

THE JOB OF THE GEOPHYSICIST*

WHAT DO GEOPHYSICISTS DO? Geophysicists make use of the basic principles of physics, mathematics, engineering, geology, and chemistry, and of various geophysical methods in studying seismic, gravitational, electrical, magnetic, and elastic characteristics of the earth, and the structure and composition of its interior and surface, including the water areas and the atmosphere. They apply the knowledge thus obtained chiefly in prospecting for petroleum, gas, and minerals. A few are engaged in making highly precise maps and charts for navigation on sea, land, and air; predicting radio-communication and atmospheric conditions; charting ocean currents; and developing water supply or flood control programs. Geophysicists are employed in two somewhat different branches: as prospectors with oil and mining companies, and as fundamental research or earth-science geophysicists with Government agencies, or academic institutions.

Geophysical Prospectors, who constitute 90 per cent of all geophysicists, use geophysical methods to find underground deposits of oil or other minerals of commercial value. For the most part they employ the seismic method which uses a seismograph to record vibrations set up by dynamite exploded under the surface. The speed and the travel time of the vibrations reveal the nature of and the distance to the underground deposits. Other techniques include: gravity methods which require torsion-balances, gravity-meters, and pendulum devices to determine where heavy undersurface masses are located; special magnetic and electrical devices which also reveal variations in the composition of underground masses; and inspection of the cores drilled from wells, cuts for highways and railways, and exposed strata of rock. The instrument recordings and other chemical and physical data are analyzed and interpreted in the light of available knowledge of the geology of an area.

The fundamental research geophysicists specialize in one of the following:

Seismologists record and study the time and place of occurrence, rate of travel, and intensity of earthquakes by use of a seismograph. Their records and test shocks help structural engineers to select safe locations for dams and to design earthquake resistant buildings. Seismologists engaged in prospecting are described in the preceding paragraph.

Hydrologists study the occurrence and movement of water on and below the surface of the earth, including precipitation; map and chart water flow and the deposit of sediments; measure changes in volume due to evaporation and snow melting; and study the nature and movement of glaciers. Their findings are used in flood or drought forecasting, planning soil and water conservation, and in planning water supply, water power, flood control, drainage, irrigation, and inland navigation projects. Work in this field is shared with geologists and hydraulic engineers.

* Occupational Brief No. 26.

Prepared by the National Roster of Scientific and Specialized Personnel of the War Manpower Commission for use in the education programs of the Armed Services.

This Brief was prepared with the help of several officers and members of the Society to whom preliminary drafts were submitted. It is reprinted as of interest to those who will be employing geophysicists or advising them with regard to training for a geophysical career. Ed.

Geodesists use precise surveying and geodetic instruments to map the earth's surface, to determine accurately geographic latitudes and longitudes and elevations above sea level, and to make surveys of coastal areas. They also use gravimetric instruments to determine variations in the earth's gravitational pull.

Volcanologists determine origin and chemical composition of volcanic rock and ore deposits, and use geodetic and magnetic techniques in studying the history and growth of volcanoes, and the mechanics of eruptions.

Oceanographers chart and study icebergs, ocean beds, tides, and currents; make chemical analyses of samples of sea water and bottom mud; study shifting and deposition of sands on beaches. Their findings provide valuable information for navigators.

Geomagneticians study the earth's internal and external magnetic fields and electrical currents; atmospheric electricity; and radioactivity of the earth, oceans, and atmosphere. Their findings are useful in radio communication and marine navigation. The allied field of *meteorology* is described in a separate brief.

Geophysicists specializing in any of the above fields may engage in one or more of the following functions: field exploration (especially applicable to geophysical prospectors); development of new methods of prospecting and surveying; field surveys (applicable to geodesists, magneticians, and hydrologists); teaching in a university; and instrument design, development, and construction.

How Do You Qualify as a Geophysicist? A few colleges and universities offer a bachelor of science degree, with a major in geophysics, and geophysics courses on the graduate level. One can also prepare for work in geophysics by first obtaining a bachelor's degree with a major in mathematics, physics, or geology; or an engineering degree, especially in the electrical, mining, or civil branches. Specialized courses in geophysics, meteorology, hydrology, and seismology, if available, are highly desirable. Most men gain their specialized training in field work under the guidance of geophysicists. One may thus spend 4 or 5 years on his formal education, plus 1 to 2 years of apprenticeship in actual work which will intensify, as well as broaden the foundation he has built.

Who Should or Should Not Take Up Geophysics? A person who has an aptitude for studying college physics and mathematics, plus an orderliness of mind for the arraying of observed facts, should make a good geophysicist. A geophysicist must frequently deal with precise measurements and complicated mathematics in order to master a theory in the earth sciences. If you served as radar operator, radar mechanic, or surveyor, or in related jobs in the armed forces, and liked the work, you may like the work of the geophysicist. Some of the tests which you may have taken in the service may supply additional information about your scientific aptitudes, but only a person who is trained to interpret these tests can tell whether or not your test scores show that you have any special abilities for a specific occupation.

Where Do Geophysicists Work, What Do They Earn, and What Is the Outlook? Most geophysicists are employed by petroleum firms, by geophysical prospecting companies, or as consultants in prospecting work. A few are in research organizations and laboratories and in the Federal service. The prewar entrance salary in private employment and in educational institutions was between $1,800 and $2,000. In Government employment the starting pay is $2,320. Through experience, the annual income will frequently increase to $5,000 and even to $10,000 per year at the height of one's career. Salaries for foreign assignments are higher than for domestic jobs. In 1940, there were 1,500 geophysicists.

Geophysics is a small though not an overcrowded field. There will probably be a gradually increasing demand for geophysicists both abroad and in the United States, especially for commercial exploration for new sources of minerals and petroleum. There may also be greater need for hydrologists if the government undertakes a broad postwar program of flood control and development of our water resources.

WHERE CAN YOU PREPARE FOR A CAREER IN GEOPHYSICS AND WHAT SUBJECTS DO YOU TAKE? You can prepare for geophysical work by attending one of the full-time colleges that offer a bachelor of science degree, preferably with a major in geophysics. You may also major in geology, mathematics, physics, or in some branch of engineering, followed by subsequent training in geophysics. In any case, geology, mathematics, and physics will be your fundamental courses, with as much chemistry and related engineering as the curriculum will permit. A number of colleges operate on the cooperative plan of part study and part work, and some colleges offer part-time evening courses in engineering. Desirable high school preparatory subjects are algebra, geometry, trigonometry, drafting, physics and chemistry.

HOW CAN USAFI HELP A SERVICEMAN TO PREPARE AS A GEOPHYSICIST? The U. S. Armed Forces Institute offers to servicemen many correspondence courses that will help to prepare a background for geophysical work, for example, J265 Mapping; C713 College Algebra and Trigonometry; C718 Integral Calculus; C724 Differential Equations; J381 Elements of Mechanics; C748 General Geology; and C750 Weather and Climate. Offered also are the following self-study courses: EM 315, College Algebra; EM 451, Introductory College Chemistry; EM 460, Outlines of Physical Chemistry; EM 469, Electricity and Magnetism; and EM 464, Physical Geology. In addition, a large number of college and university correspondence courses are available to servicemen through USAFI. Local off-duty classes may be set up by your educational officer.* For more information about the above courses, consult both the USAFI catalog and Information Bulletin, and your educational officer.*

HOW CAN YOU APPLY FOR ACADEMIC CREDIT FOR MILITARY EXPERIENCE? Most civilian educational institutions will grant credit for your military training, experience, and off-duty study. The schools and colleges will decide, however, whether or not you are entitled to credit. To apply for credit while you are still in the service, get USAFI Form 47 (Application for Credit for Educational Achievement During Military Service) from your educational officer, the nearest oversea USAFI branch, or USAFI, Madison 3, Wis. Fill out the form and mail it to the school or college of your choice along with a letter indicating that you are planning to prepare to be a geophysicist. Also, you may ask the school or college to recommend specific courses (USAFI, Marine Corps Institute, Coast Guard Institute, or university correspondence) that will be acceptable for additional credit.

Depending on the amount of high school work you have already completed acceptably, you may work toward or possibly complete your high school diploma requirements while in service by using USAFI Form 47 and by passing such USAFI examinations or completing such USAFI courses as your high school may require. If you have finished high school, use USAFI Form 47 and write to the college of your choice asking

* Army—Information-Education Officer; Navy—Educational Services Officer, Education Officer, or Training Officer; Marine Corps—Special Services Officer; and Coast Guard—Educational Officer.

what procedures you should follow in making application for admission and what, if any, credit will be granted. If you have already done some college work use the same method to find out if you can get credit toward your degree. For full information see the officer at your station or base who handles off-duty educational activities.

If you are a veteran, use in place of USAFI Form 47 a certified copy of your separation record (Army—WD AGO Form 100; Navy—Nav Pers 553; U. S. M. C. Report of Separation; Coast Guard, 553).

WHERE CAN YOU FIND OUT MORE ABOUT GEOPHYSICS AND RELATED EDUCATION? You can get information about schools and colleges that give work in geophysics by writing to the American Geophysical Union, 5241 Broad Branch Road NW., Washington 15, D. C., or to the Society of Exploration Geophysicists, Hamilton, Tex. Your educational officer may be able to help you. Information about geophysics can be found in the Army Vocational Information Kit and the Navy Occupational Information File if one is available at your station. Veterans may get information, especially about government financial aid for education, at the nearest Veterans Information Center.

WHAT JOBS ARE RELATED TO GEOPHYSICS? You may be interested in a career along geophysical lines, but may not want to take four years of college work. There are many opportunities for work in subprofessional or skilled trade jobs on field parties, and in assisting geophysicists in the laboratory and office. Such mathematics, physics, and surveying as you are able to obtain will be of help in this connection. An enterprising man can advance through such experience, though much more slowly than one with a better educational background.

FORECASTING EARTHQUAKES*

BY REV. J. B. MACELWANE

It was twelve minutes after five in San Francisco on the fateful morning of April 18, 1906. Most of the city's inhabitants were still in bed when the earthquake struck and the Great San Francisco Fire was started. Why was the public not warned of the coming catastrophe? Why were the people of San Francisco not told of the imminent danger of the earthquake so that they could save themselves and their movable possessions? Why were the city officials not alerted so that the gas and electricity could be cut off? We may ask similar questions about our other destructive earthquakes—about New Madrid and Charleston, about Santa Barbara and Long Beach, about Helena and El Centro.

Why do we not have an earthquake forecasting service to parallel the United States Weather Bureau? Storms are forecast; why not earthquakes? From time to time articles have appeared in the newspapers about men who claimed to have arrived at a complete solution of the problem of earthquake forecasting. They give you long lists of supposed verifications to prove the success of their predictions. Some forecasters base their predictions on the influence of the Moon, others on the relative position of certain planets, others on sunspot activity, and no doubt there are persons entirely sincere who are allured and deceived by a specious theory and by a series of apparent verifications, but who lack sufficient scientific background to make a critical appraisal of the factors involved.

* Text of a talk broadcast by Father Macelwane on Sunday afternoon, January 13, over C.B.S. network in connection with the Philharmonic Symphony Concert sponsored by United States Rubber Company. Published by permission of United States Rubber Company.

No doubt, too, there are charlatans and notoriety seekers. But seismology, the study of earthquakes, is a highly technical science, and it must be pursued by the patient, objective, fact-seeking method of scientific research.

If the earthquake prediction is made general enough, it will not be difficult to find some earthquake that would seem to verify it. Therefore, it is essential, before we proceed further in the discussion, that we clarify our ideas. We must be sure that we are all talking about the same thing.

It is not enough to predict that earthquakes will continue to occur in the future. To a person with any knowledge of earth science, that is an obvious truth. Actually more than one million earthquakes occur every year. Would I be forecasting in any true sense if I told you an earthquake will occur in Japan next week? Any experienced seismologist knows that, on the average, two dozen earthquakes occur in Japan every week. My prediction of an earthquake in Japan next week would be a statement of a moral certainty; but it would be too vague to be of any help as a forecast. What then is a forecast?

A forecast, in the modern sense, is not a mere guess. Neither is it a prophecy.

A forecast is a definite statement in regard to the sequence of future events, based on a balancing of probabilities derived from experience, observation, and the laws which are known to govern such happenings. I think we can agree, from the analogy of weather forecasting, that an earthquake prediction would not be called an earthquake forecast unless it were sufficiently probable and specific to serve a useful purpose. A public prediction of an earthquake will be useful if it serves to protect life and property without arousing undue panic.

An earthquake forecast must be *specific*. This means that the forecaster must predict three things about the earthquake. In the first place, the forecast must announce the *time* of the earthquake, at least within a few hours. Secondly, the forecast must specify the *intensity* of the coming earthquake or the extent of the damage to be expected from it. Thirdly, the forecast must state in just what *place* or *places* the destruction of property is going to occur.

Besides being specific, the forecast must also be *reliable*. That is, a predicted disaster must be sufficiently probable to justify public authorities in removing the threatened populations, cutting off the gas supply and the electricity, and otherwise disrupting the normal life of the people. The mere heralding of a disastrous earthquake would create a panic and might drive many people insane.

Is it possible, in the present state of scientific knowledge, to predict earthquakes in this definite and positive sense which alone deserves the name of forecasting? Unfortunately, no! All reputable seismologists agree that we have no means at the present time of arriving at a reliable forecast of any earthquake anywhere.

The problem of earthquake forecasting has been under intensive investigation in California and elsewhere for some forty years; and we seem to be no nearer a solution of the problem than we were in the beginning. In fact the outlook is much less hopeful.

In the California earthquake of 1906, the earth was torn by a crack or fault which extended more than 150 miles in a north-northwest south-southeast direction. All structures, roads, fences, rows of trees, which crossed this fault were rent apart and offset. The portion on the west side of the crack was permanently shifted toward the north, relative to that on the east side of the fault. The horizontal offset, or shift, between the two parts originally continuous across the fault, amounted in one case to as much as twenty-one feet.

Immediately after the earthquake, the United States Coast and Geodetic Survey made a resurvey of the area and found that points many miles west of the fault had been displaced northward and points east of the fault had been displaced southward. These scientists also found that the regional shifts were made up of two parts. There was a smaller shift which had occurred sometime between the years 1866 and 1874, and a larger shift that had taken place between 1892 and July, 1906. In the first of these intervals, the earthquake of 1868 had occurred with relative movements on the Haywards fault east of San Francisco Bay. In the second interval was the earthquake of 1906, which involved the relative displacements we have described along the San Andres fault west of the San Francisco Bay.

To explain these distinct sets of movements, a well-known seismologist proposed the theory of a slow northward creep of the coastal region, which creep gradually distorted the rocks in that portion of the earth's crust until they were strained beyond their capacity to resist. When this limit was reached, fracture occurred along the weakest zone, and the rocks on both sides of the fault rebounded elastically to new positions of equilibrium. It was as if the Pacific coast started on a vacation trip to Alaska and the rest of California refused to go along and held back until their rock mantle tore.

"Ah!" said the seismologists, "here is a means of forecasting earthquakes. Measure the gradual creep. When the shear approaches the ultimate strength of the rocks, there will soon be an earthquake." So concrete pillars were placed on both sides of the San Andres fault and their relative positions were determined very accurately with surveying instruments. The relative positions have been redetermined again and again in succeeding years, but no trace of creep has been observed.

"The pillars were placed too close together," said the seismologists. "Let us set up a precise network of triangulation stations and lines of leveling and let us repeat the measurements after a few years." The United States Coast and Geodetic Survey repeated its survey of California. This was done in the early twenties. No sure sign of regional creep was found. Then a very dense network of triangulation and leveling stations was laid across the faults in southern California and another in central California. So far, no evidence of regional creep has appeared.

The Japanese claimed to have observed a tilting of the ground before an earthquake. American seismologists eagerly seized on this as a possible means of forecasting earthquakes and set up tiltmeters at Berkeley, California.

Tilts were observed and so were earthquakes of very near origin. But unfortunately there was no correlation between the tilts and the earthquakes.

Do earthquakes come in cycles? Can they be triggered by weather or tidal action? If so, they might be forecast. Many statistical studies were made; but the conclusions were all negative or very uncertain.

Every lead that was suggested has been followed and all of them so far have led up blind alleys. Of course, earthquake prediction in a wider sense is possible. We know from history and from the records of modern seismographs that many more earthquakes occur in certain parts of the world than in others. The rim of the Pacific Ocean is particularly active. No year passes without a strong earthquake somewhere in the lands that border the Pacific Ocean. The same is true of most of the larger groups of islands in the Pacific. Hence one needs only to make his prediction broad enough in space and time and it is sure to be verified. But this is not earthquake forecasting as we have defined it and as forecasting is usually understood.

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During his fifteen years of continuous employment with Gulf Research & Development Company, he has spent thirteen years (1930–43) in the interpretation of magnetic data and two years (1944–46) in the interpretation of seismic data.

He is a member of the American Geophysical Union, the Oil and Gas Section of the Engineers' Society of Western Pennsylvania and of the Society of Exploration Geophysicists.

H. WAYNE HOYLMAN

HERBERT E. HAWKES received the degrees of B.A. from Dartmouth College in 1934, and Ph.D. from the Massachusetts Institute of Technology in 1940. In 1936 and 1937 he was engaged in geophysical exploration for Hans Lundberg, Ltd., Toronto; from 1940 to date he has been employed with the U. S. Geological Survey in geological and geophysical exploration work principally on chromite and magnetite. He is a member of the American Geophysical Union, the Geological Society of Washington, the American Association for the Advancement of Science and of the Society of Exploration Geophysicists.

HERBERT E. HAWKES

G. M. KINTZ

G. M. KINTZ obtained a degree of Engineer of Mines with a major in oil geology from the Colorado School of Mines. After leaving school, he worked in the metal mines in Arizona and New Mexico and then went with an oil company as assistant geologist in Oklahoma during the time the Osage Nation was being developed. From there, he went into oil shale work and assisted in operating the only successful oil shale plant in the United States, which was at Elko, Nevada. From the experience derived there, he did mining engineering and geology work for the U. S. throughout the Western United States. He entered the Safety Division of the Bureau of Mines in 1926 and in 1937 was placed in charge of District G of the Health and Safety Branch of the Bureau of Mines, with headquarters at Dallas, Texas. The war activities of the Health and Safety Branch of the Bureau of Mines included the administration of the Federal Explosives Act.

H. P. BOOTS

PAUL H. BOOTS received his B.A. degree in Physics from the University of Wisconsin in 1930 and his M.A. degree in 1931. He was employed by the Allen-Bradley Company in their research laboratories in Milwaukee, Wisconsin for two years. From January 1933, until May, 1944, he was employed by the Gulf Research & Development Company in seismograph work. During that time he worked in California, Mexico, Venezuela, Kuwait and England. Since May, 1944, he has been Assistant Manager for the Colombian Gulf Oil Company with headquarters in Bogotá, Colombia.

He is a member of the American Physical Society, American Geophysical Union, American Association of Petroleum Geologists and of the Society of Exploration Geophysicists.

ALEXANDER H. MCKEE received the degree of Civil Engineer from Rensselaer Polytechnic Institute in 1930. He was an instructor in civil engineering at Rensselaer in 1931 and 1932. From 1933 to 1936 he traveled extensively in the United States as an observer on an astronomic party of the U. S. Coast and Geodetic Survey. Since 1936 he has been employed in various geophysical capacities by the Gulf Research and Development Company in the United States, the Middle East, England, and Denmark. He is a member of the American Association of Petroleum Geologists.

ALEXANDER H. MCKEE

Photographs and biographies of contributors to this issue not appearing above have been published previously, as follows: ALFRED WOLF, Vol. VII, No. 4, p. 428 (October, 1942). C. W. HORTON, Vol. VIII, No. 3, p. 318 (July, 1943). E. G. KOGBETLIANTZ, Vol. IX, No. 4, p. 573 (October, 1944).

THE SOCIETY ROUND TABLE

APPLICATIONS FOR MEMBERSHIP APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the Secretary within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

Augusteijn, J. J.
C. H. Gregory, A. Klein-Haneveld, G. L. Barksdale

Brant, Arthur Albert
J. H. Hodgson, Theo. Koulomzine, Art. III-D-1 of Constitution

Cline, Albert Francis
V. L. Jones, Stefan Von Croy, Joseph A. Sharpe

Cook, Paul Chronical
C. C. Zimmerman, S. P. Weatherby, H. W. McDonnold

Cronin, Stewart
W. W. Newton, Ira H. Cram, E. E. Wilson

Edmonson, Carl Louis
Geo. E. Wagoner, Robert J. Watson, A. B. Bryan

Fillippone, Walter Ross
Barthold W. Sorge, Maynard W. Harding, William Howard Myers

Fishback, Joseph W.
K. E. Burg, Karl Dyk, M. D. Tucker

Foster, Gale Allen
Joseph A. Sharpe, V. L. Jones, Stefan Von Croy

Garpner, Erik Uno
Joseph A. Sharpe, V. L. Jones, A. C. Reid

Gibson, George Drew
Joseph A. Sharpe, R. H. Tucker, W. Lee Moore, Jr.

Hammitt, Philip
J. H. Deming, L. W. Saunders, E. H. Vallat

Harris, Jack Austin
Neal J. Smith, James H. Todd, E. T. Nichols

Hughson, Barrett Burke
H. R. Thornburgh, K. S. Cohick, H. L. Thompson

Ivanhoe, Lytton Francis, Jr.
John Marston, R. E. McMillan, K. H. Odenweller

Lockwood, Robinson Peale
L. J. Peters, L. L. Nettleton, L. W. Gardner

Lyons, Paul L.
Geo. E. Wagoner, R. W. Gemmer, H. Wilder Brown

Parr, Josephus Overton, Jr.
Harlan Taylor, P. E. Narvarte, Joe Bill Barbisch

Poldini, Edward Maria
E. G. Leonardon, E. F. Stratton, Art. III-D-1 of Constitution
Ramirez, John Moya
B. W. Sorge, M. H. Harding, F. H. Agee
Reed, David Eddleman
Joseph A. Sharpe, V. L. Jones, R. C. Coffin
Reiser, Robert George
E. A. Eckhardt, L. L. Nettleton, S. I. Hammer
Rice, Robert Bruce
R. G. Piety, C. C. Crenshaw, A. J. Hintze
Robert, Kearny
Neal J. Smith, James H. Todd, L. I. Brown
Ross, John Wyckliff
Joseph A. Sharpe, V. L. Jones, Stefan Von Croy
Rusch, Peter John
L. J. Neuman, W. D. Neff, A. J. Barthelmes
Sauvé, Nathaniel Bernard
B. O. Winkler, G. F. Kaufmann, J. K. Dahlberg
Snedden, Loring B.
Wallace L. Matjasic, John Sloat, T. P. Ellsworth
Walling, Ray William
K. E. Berg, M. B. Widess, Karl Dyk
Walton, Britain Williams
W. Harlan Taylor, P. T. Rumsey, Chester Sappington

ASSOCIATE

Allen, William Edward
R. L. Kidd, R. M. Bradley, H. B. Ericson
Dausman, Russell Hudson
Roy L. Lay, L. G. Cowles, Alexander Wolf
El-Barkovky, Ahmed Nasr
J. Carr, and Art. III-D-1 of Constitution
Godell, John J.
H. C. Cortes, P. E. Nash, J. C. Menefee
Heard, James Richard
A. C. Yokubaitis, V. E. Child, O. T. Lawhorn
Holser, William Thomas
Beno Gutenberg, Bernardo Grossling, Benj. Howell
Stimler, Saul
L. A. Cornish, R. W. Mossman, Carl Blakey

STUDENT

Brown, Frederick Wallace
John H. Hodgson, Art. III-D-1 of Constitution

TRANSFER FROM ASSOCIATE TO ACTIVE

Broussard, C. H.
Fischer, L. F.

Hargis, A. V.
Hopkins, James Stinson
Low, R. M.
Schultis, G. E.

RE-INSTATEMENT

Newby, C. J.

RESIGNATIONS

Daly, John W.
Jaques, Alvin T.
Washburn, Harold W.

PERSONAL ITEMS

JOE R. BRADLEY, JR., with the Stanolind Oil & Gas Company, has left Crowley, La., and is with Seismograph Party #12 at Box 659, Casper, Wyo.

E. DARRELL WILLIAMS has been operating for some time out of Lander, Wyo., but is now back in his office at 2732 Pittsburg St., Houston 5, Texas.

NAT H. PRADE, recently released from military service, is back at work in South America, with the Caribbean Petroleum Company, Geophysical Section, at Maracaibo, Venezuela.

LT.-COMDR. FIELDING L. MITCHELL, U.S.N.R., recently of the Fleet Post Office, San Francisco, is now on duty at the Naval Research Laboratory, Washington, D. C. His personal address is 719 South Royal St., Alexandria, Va.

CARL W. BLAKEY has recently been transferred to foreign service by the Seismograph Service Corporation, and will for the present be stationed as supervisor for that company at Box 309, Haifa, Palestine.

E. L. MILLER, JR., is now Assistant Professor of Geological Engineering at North Carolina State College, Raleigh, N. C. He may be personally addressed at Box 5606, Raleigh, N. C.

EDWARD D. LYNTON has been appointed Oil Consultant to the French Government for a period of two years, to assist them in their oil development of France; and for that purpose, has been granted leave of absence by the California Research Corporation, a subsidiary of the Standard Oil Company of California. Mr. Lynton, with Mrs. Lynton and their 14-year-old son, Dennis, sailed from New York early in February for Paris. Mail will reach him if addressed in care of Mrs. T. J. Potter, 702 North Central Ave., Glendale 3, Calif.

T. C. RICHARDS, formerly with the Anglo-Iranian Oil Co., Ltd., London, has recently been transferred to the Anglo-Bahamian Oil Co., Ltd., and is stationed at Nassau, Bahama Islands. His address is Box 376, Nassau.

ALBERT W. MUSGRAVE, until recently RT/2C at the Naval Repair Base at San Diego, Calif., has been released from service and is vacationing at home (c/o Real Musgrave, Hugo, Colo.) before re-entering the Colorado School of Mines for his last semester.

ROBT. L. GEYER, who put in war-time service with the Rohr Aircraft Corp. of California, is back with the Seismograph Service Corporation, working as computer with a field party in central Venezuela. His address is Aptdo. 1488, Caracas, Venezuela.

After a brief vacation in Texas, HOLLOWAY FROST has left for Egypt, where he will be Geophysicist for the Socony-Vacuum Oil Company, at 62 Sharia Ibrahim Pasha, Cairo, Egypt. "Hal" recently returned from Venezuela, where he has been stationed since joining Socony, in 1941. Previous to that date he had been with Mott-Smith Corporation in Venezuela and Egypt. Mrs. Frost and son "Holly," who was born in Venezuela, are accompanying him to Egypt.

R. E. BLIGHT, formerly with the Amerada, is now a Party Chief with Yegua Corporation, 2302 Esperson Bldg., Houston 2, Texas.

DAVID W. RATLIFF, Seismic Party Chief with Stanolind Oil and Gas Company, is currently stationed with Party 23, P. O. Box 110, Houma, La.

V. ROBERT KERR is leaving Cities Service Oil Company after twelve years in seismic exploration work, and will be associated with Sidney Schafer, Consulting Geophysicist, at 3775 Harper St., Houston 5, Texas.

ROBERT S. DAHLBERG, JR., has been sent to Venezuela, where he is with the Creole Petroleum Corporation, at Caracas, Aptdo. 889.

D. G. EGAN, lately a Captain with Company D, 3118 Sig. Serv. Group, A.P.O. New York, is now on duty with the Geophysical Division, Carter Oil Company, Tulsa, Okla.

G. L. BARKSDALE, with the Petty Geophysical Engineering Co. and recently at Quito, Ecuador, is now stationed at Ambato, Ecuador, Casilla Correo 260.

HARRY R. IMLE is released from Field Artillery service, and back with the Carter Oil Company. At present he is at Rawlins, Wyo., Box 503.

D. C. BOWMAN, with Seismograph Service Corporation, has been transferred to their Tulsa laboratory, as technician. His address is 2620 E. Archer, Tulsa, Okla.

C. M. ENGLAND, Seismic Interpreter with the Stanolind Oil and Gas Company, has been moved to Ft. Worth, and may be addressed there at Box 1410.

H. J. MCCREADY, JR. (formerly Ensign) is now with E. V. McCollum Company, 1510 Thompson Bldg., Tulsa 3, Okla.

Among others who have been released from military service in late months, but of whose present business connections no notice has been received, are:

(MAJOR) W. E. STEELE, JR., back from Washington, D. C., and located at 2114 Elmen, Houston, Texas.

(CAPT.) LOUIS C. PAKISER, JR., now at 480 So. Raleigh St., Denver 9, Colo.

(LT.-COMDR.) JOHN H. CROWELL, back from the South Pacific, and at home at 3416 Ella Lee Lane, Houston, Texas.

ODELL C. OLSEN (lately Capt. Olsen, c/o F.P.O., San Francisco) is now with the Texas Railroad Commission, Oil and Gas Division, at Midland, Texas.

C. H. GERDES, after serving with the Petroleum Administration for War, has moved from Alexandria, Va., and is now with United Geophysical Company, 595 E. Colorado St., Pasadena 1, Calif.

MISS RUTH BREEDLOVE, computer with the Atlantic Refining Co., is now at Box 150, Elk City, Okla.

R. T. PENNY, Party Chief with Independent Exploration Company, may be addressed at 115 So. 19th St., Baton Rouge, La.

MILTON C. BORN, long with Amerada Petroleum Corporation at Tulsa, has been

transferred by that company to California, and may be addressed in its care at 552 Subway Terminal Bldg., Los Angeles 13, Calif.

DR. MAURICE EWING, who has done distinguished service at the Woods Hole Oceanographic Institution, Woods Hole, Mass., during the war, is now on the staff of the Department of Geology at Columbia University (New York 27, N. Y.)

DAVID M. WEBER, recently of the Pittsburgh office of the Gulf Research and Development Company, has been transferred to the Mene Grande Oil Company, and will be at Aptdo 234, Maracaibo, Venezuela, S. A.

J. B. SOUTHER, Geophysicist and Consulting Geologist, whose home address is 1930 F. St., Lincoln, Nebraska, expects to make an extended stay in Honduras, where he will be in charge of development of large timber concessions for the Honduras Timber & Exploration Co., San Pedro Sula, Honduras, C. A.

KIRBY, J. WARREN, with the Carter Oil Company, lately at Rawlins, Wyo., is now stationed at Billings, Mont., where his address is Box 2104.

COL. JOHN V. LONG has moved from the Inspector General's Dept., Washington, D. C., to 4120 Fifth Ave., San Diego 3, Calif.

E. H. VALLAT, of the Ohio Oil Company, is now located in Bakersfield, Calif., at 208 Lincoln Street. The Company address is Box 193, Bakersfield.

DR. JOSHUA L. SOSKE, whose professional card address was unfortunately in error in the last issue, is now to be addressed at P. O. Box 7, Station C, Pasadena 6, Calif.

THEO. ROZSA has moved from Midland Texas, to Box 1817, Jackson, Miss.

Pennsylvania State College has prepared Circular No. 20, "Opportunities for Productive Work through Mineral Industries Research." This is a handsomely illustrated pamphlet of thirty-six pages devoted to research at Penn State in mineral industries, particularly those of the state of Pennsylvania, and to the organization and activities of the Mineral Industries Experiment Station. Copies may be obtained free from the director of Mineral Industries Experiment Station, Pennsylvania State College, State College, Pa.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS
CONSTITUTION AND BY-LAWS

(As amended to April, 1943)

I. Name

This Association shall be called the "Society of Exploration Geophysicists."

II. Object

The object of this Association is to promote the science of geophysics especially as it applies to exploration.

III. Membership

A—Members

1. Any geophysicist of recognized standing shall be eligible to membership, whether or not he is engaged in petroleum geophysics or in geophysical prospecting.
2. Any physicist, mathematician, geologist, or engineer of recognized standing who is investigating a geophysical problem or problems shall be eligible to membership.
3. Any geologist of recognized standing who is not a geophysicist of recognized standing, but who is acting as chief, or division chief in charge of geophysical surveying, shall be eligible to membership.

B—Associates

1. Any geophysicist, geologist, engineer, mathematician, or physicist who is a graduate of an institution of recognized scientific standing who is engaged in geophysics and who is not eligible to membership shall be eligible to associate membership.
2. Any person who is not a graduate of an institution of recognized scientific standing and who is not eligible to membership and who has shown ability in a routine phase of geophysical work and who is in a position of responsibility in geophysical surveying shall be eligible to associate membership.
3. Any representative or employee of a firm or corporation engaged in supplying equipment or supplies to the geophysical prospecting industry, provided such individual is the graduate of an institution of recognized scientific standing, or provided otherwise that such individual is qualified by adequate technical experience, shall be eligible to associate membership.
4. Associate members shall be known as associates.
5. Associates shall enjoy all the privileges of membership in the Society, save that they shall not hold office, sign applications for membership, or vote; neither shall they have the privilege of advertising their affiliation with the Society in professional cards or professional reports or otherwise.
6. The Executive Committee may advance to active membership, without the formality of application for such change, those associates who have, subsequent to election, fulfilled the requirements for active membership.

C—Student Members

1. Any graduate or undergraduate student in residence at a recognized university or college shall be eligible for student membership.

2. Student membership shall terminate one year after a student member ceases to be enrolled at a recognized university or college.
3. The privileges of student members shall be the same as those of associate members.

D—Election to Membership

1. Every candidate for admission as a member or associate shall submit a formal application on an application form authorized by the Executive Committee, signed by him, and endorsed by not less than three members who are in good standing, stating his training and experience and such other facts as the Executive Committee shall from time to time prescribe. Provided the Executive Committee, after due consideration, shall judge that the applicant's qualifications meet the requirements of the Constitution, they shall cause to be published in an appropriate publication the applicant's name and the names of his sponsors. If, after at least thirty days have elapsed since such publication, no reason is presented why the applicant should not be admitted, he shall be deemed eligible to membership or to associate membership, as the case may be, and shall be notified of his election. Provided the Executive Committee may accept applicants for either class of membership, who, because of their geographical location or because of their lack of acquaintance with active members of this Society, are unable to secure qualified sponsors, but who otherwise are eligible for membership. Applicants for student membership may be accepted as student members upon recommendation of a faculty member of the school they are attending, and with the unanimous approval of the Executive Committee.
2. An applicant for membership, on being notified of his election in writing, shall pay full membership dues for the current year and on making such payment shall be entitled to receive the regular Society publications for that year. Unless payment of dues is made within thirty (30) days by those living within the continental United States and within ninety (90) days by those living elsewhere, after notice has been mailed of his election, the Executive Committee may rescind the election of the applicant. Upon payment of dues, each applicant for membership shall be furnished with a membership card for the current year and until such written notice and card are received, he shall in no way be considered a member of the Society.

E—Honorary Members

1. The Executive Committee may from time to time and by unanimous action elect as honorary members persons who have contributed distinguished service to the cause of geophysics. Honorary members shall not be required to pay dues.

F—Code of Ethics

1. Membership of any class shall be contingent upon conformance with the established principles of professional ethics.

IV

A—Resignation—Suspension—Expulsion

1. Any member or associate may resign from the Society at any time. Such resignation shall be in writing and shall be accepted by the Executive Committee,

subject to the payment of all outstanding dues and obligations of the resigning member or associate.

2. Any member or associate who is more than one year delinquent (in arrears) in payment of dues shall be suspended from the Society. Any delinquent or suspended member or associate, at his own option, may request in writing that he be dropped from the Society and such request shall be granted by the Executive Committee. Any member or associate more than two years in arrears shall be dropped from the Society. The time of payment of delinquent dues for either one year or two years may be extended by unanimous vote of the Executive Committee.
3. Any member or associate who resigns or who is dropped under the provisions of Sections 1 and 2 of this article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.
4. Any person who has ceased to be a member or associate under Section 1 or Section 2 of this article may be re-instated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member or associate of the Society.
5. Any member or associate who, after being granted a hearing by the Executive Committee, shall be found guilty of a violation of the code of ethics of this Society or shall be found guilty of a violation of the established principles of professional ethics, or shall be found guilty of having made a false or misleading statement in his application for membership in the Society, shall be asked to resign from the Society by unanimous vote of the Executive Committee. The decision of the Executive Committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

V. Officers and Their Duties

A—Officers

1. The officers of the Society shall be a President, a Vice-President, a Secretary-Treasurer, and an Editor. These, together with the Past President, shall constitute the Executive Committee and managers of the Society. Officers shall be elected for a term of one year with the exception of the Editor, who shall be elected for a term of two years.
2. A ticket of nominations for officers and representatives shall be prepared by a Committee on Nominations which shall consist of the President and the two qualified Past Presidents in order of precedence. Favorable action of this Committee shall be two out of three votes. This Committee shall nominate two candidates for President, one of whom shall be the retiring Vice President, and two candidates for each of the other offices to be filled.

   The ticket prepared by the Nominating Committee, as well as any other ticket presented in writing and signed by at least twenty members in good standing, shall be submitted to the President by November 30. The President shall secure written acceptance of nominations from each candidate. The names of nominees shall be placed on the official ballot which shall be mailed to each member not later than December 15. Names of candidates shall be listed alphabetically except that the name of the retiring Vice-President shall occupy

first place on the ticket. Blank spaces shall be provided on the ballot for writing in nominations for each office.

Each member shall cast one vote for each officer to be elected and shall return his ballot to the Secretary-Treasurer. Ballots to be valid must be enclosed in an envelope carrying on the outside the written signature of the member submitting the ballot, and must be received by the Secretary-Treasurer at his officially recognized address not later than ten days prior to the Annual Meeting. Only ballots received from members in good standing as of a date ten days prior to the Annual Meeting shall be valid. The Secretary-Treasurer shall indicate which ballots are valid by initialing the enclosing envelope and shall deliver the ballots unopened to the Nominating Committee for counting.

The Nominating Committee shall count the ballots immediately before the Annual Business Meeting. The candidate receiving the greatest number of valid votes cast for an office shall be declared elected to that office. In case of a tie, the Nominating Committee shall decide by a secret vote which of the candidates tied shall be elected.

The announcement of the election shall be made as the first of the new business considered at the Annual Meeting.

3. No one shall hold the office of President for two consecutive years and no one shall hold any other office for more than two consecutive years except that of Editor.

B—Duties of Officers

1. The President shall be the presiding officer at all the meetings of the Society, shall take cognizance of the acts of the Society and of its officers, shall appoint such committees as are required for the purposes of the Society, and shall delegate members to represent the Society. He may, at his option, serve on, and may be chairman of, any committee.
2. The Vice-President shall assume the office of President in case of a vacancy from any cause in that office and shall assume the duties of President in case of the absence or disability of the latter. He shall also act as Chairman of the Program and Arrangements Committee of the Society.
3. The Secretary-Treasurer shall assume the duties of the President in case of the absence of both the President and Vice-President. He shall have charge of the financial affairs of the Society and shall annually submit reports as Secretary-Treasurer covering the fiscal year, which he shall arrange to have published in the next regular issue of the recognized organ of the Society. He shall receive all funds of the Society and, under the direction of the Executive Committee, shall disburse all funds of the Society. He shall cause an audit to be prepared annually by a public accountant at the expense of the Society. He shall give a bond, and shall cause to be bonded, all employees to whom authority may be delegated to handle Society funds. The amount of such bonds shall be set by the Executive Committee and the expense shall be borne by the Society. The funds of the Society shall be disbursed by check as authorized by the Executive Committee.
4. The Editor shall be in charge of the editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the regular Society publication and for special publications, and may accept

or reject material offered for publication. He may appoint associate, regional, and special editors.

5. In the event of absence, disability or resignation of any member of the Executive Committee, the vacant place in the Committee shall be automatically filled by the next preceding qualified Past President who shall be known as Prior Past President.
6. The officers shall assume the duties of their respective offices immediately after the Annual Meeting following their election.

VI. Executive Committee—Meetings and Duties

A—Executive Committee

1. The Executive Committee shall consist of the President, Past President, Vice-President, Secretary-Treasurer, and Editor.

B—Meetings and Duties

1. The Executive Committee shall meet preceding the annual meeting and at the call of the President may hold meetings when and where thought advisable, to conduct the affairs of the Society. A joint meeting of the outgoing and incoming Executive Committees shall be held immediately after the close of the annual Society business meeting. Members of the Executive Committee may vote by proxy, mail or person on all matters which call for favorable or unanimous action.
2. The Executive Committee shall consider all nominations for membership and pass on the qualifications of the applicants, shall have control and management of the affairs and funds of the Society, shall determine the manner of publication and shall designate the place of the annual meeting. They are empowered to establish a business headquarters for the Society, and to employ such persons as are needed to conduct the business of the Society. They are empowered to make investments of both general and special funds of the Society. Trust funds may be created giving to the trustees appointed for such purposes such discretion as to investments as seems desirable to the Executive Committee to accomplish any of its objects and purposes, but no such trust funds shall be created unless they are revocable upon ninety (90) days' notice. Favorable action shall consist of a favoring three out of five votes. Committee members may vote by person, proxy or in writing.

VII

A—Meetings

1. The Society shall hold at least one stated meeting each year, which shall be the annual meeting. This meeting shall be held at a time and place designated by the Executive Committee. At this meeting the proceedings of the preceding meeting shall be read, Society business shall be transacted, scientific papers shall be read and discussed, and results announced by the mail ballot for officers for the ensuing year.

VIII

A—Amendments

1. Amendments to this Constitution may be proposed by a resolution of the Executive Committee, by a Constitutional Committee appointed by the President,

or in writing by any ten members of the Society. All such resolutions or proposals must be submitted at the annual meeting of the Business Committee of the Society as provided in the By-Laws, and only the Business Committee shall make recommendations concerning proposed constitutional changes at the annual Society business meeting. If such recommendations by the Business Committee shall be favorably acted on at the annual Society business meeting, the Secretary-Treasurer shall arrange for a ballot of the membership by mail within thirty (30) days after said annual Society business meeting, and a majority vote of the ballots received within ninety (90) days of their mailing shall be sufficient to amend. The legality of all amendments must be determinted by the Executive Committee prior to balloting.

B—Parliamentary Regulations

1. The rules contained in "Robert's Rules of Order, Revised" shall govern the Society in all cases to which they are applicable, and in which they are not inconsistent with the By-Laws or the special rules of order of this Society.

BY-LAWS

I

A—Dues

1. The fiscal year of the Society shall correspond with the calendar year.
2. The annual dues of members of the Society shall be five dollars ($5.00). The annual dues of associates for not to exceed six years after election shall be four dollars ($4.00); thereafter, the annual dues of such associates shall be five dollars ($5.00). The annual dues of student members shall be three dollars ($3.00). The annual dues are payable in advance on the first day of each calendar year. A bill shall be mailed to each member, associate, and student member before January first of each year, stating the amount of the annual dues and the penalty and conditions for default in payment. Members, associates, or student members who shall fail to pay their annual dues by March fifteenth shall not receive further copies of the regular Society publication, shall not be eligible to vote, nor shall they be privileged to buy Society special publications at prices made to the membership, until such arrears are met.

II

A—Publications

1. The proceedings of the annual meeting, the Constitution and By-Laws, and the papers presented at such meeting shall be published at the discretion of the Executive Committee in the regular publication or in such other form as the Executive Committee may decide best meets the needs of the membership of the Society.
2. The payment of annual dues for any fiscal year entitles the member or associate to receive without further charge the regular publication of the Society for that year. $3.00 ($3.50 foreign) of the annual dues is set aside for payment of the annual subscription to the Society Journal, GEOPHYSICS.
3. The Executive Committee may authorize the printing of special publications to be financed by the Society from its general, publication or special funds and

offered for sale to members and associates in good standing at not less than the cost of publication and distribution.

4. The Executive Committee may authorize the awarding of suitable prizes for the best papers submitted for publication in GEOPHYSICS under conditions designated by it.

III

A—Regional Sections, Technical Divisions, and Affiliated Societies

1. Regional sections of the Society may be established provided the members of such sections are members of the Society and shall perfect an organization and make application to the Executive Committee. The Executive Committee shall submit the application for action first by the Business Committee and second to the Society for a letter ballot as for a constitutional amendment, and provided that the Society may revoke the charter of any regional section by similar action.
2. The Executive Committee may arrange for the affiliation with the Society of duly organized groups or societies, which by object, aims, constitution, by-laws, or practice are developing the study of geophysics or petroleum technology. In like manner, the Executive Committee may arrange conditions for dissolution of such affiliations. Affiliation with the Society need not prevent affiliation with other scientific societies. Members of affiliated societies who are not members of the Society, shall not have the privilege of advertising their affiliation with the Society on professional cards or otherwise, but shall be entitled to receive the regular publication of the Society upon payment of a fee equivalent to that charged an associate member.

IV

A—District Representatives

1. The Executive Committee may cause to be elected district representatives from districts which it shall define by a local geographic grouping of the membership. Such districts shall be redesignated and redefined by the Executive Committee as often as seems advisable. Each district shall be entitled to one representative for each seventy-five members, but this shall not deprive any designated district of at least one representative. The representatives so apportioned shall be chosen from the membership of the district by a written ballot arranged by the Executive Committee. They shall hold office for two years, their term of office expiring at the close of the annual meeting. In so far as possible, these two-year terms shall be overlapping.

V

A—Business Committee

1. The Business Committee shall be a standing committee of the Society to act as a council and advisory board to the Executive Committee and the Society. This Committee shall consist of the Executive Committee, the Prior Past President, and the district representatives. Favorable action by the Business Committee shall consist of a favorable two-thirds vote. The Secretary-Treasurer shall act as Secretary of the business meeting. Members of this Committee may vote in person, by proxy, or in writing. The Business Committee shall meet the day before

the annual meeting at which time proposed changes in the Constitution or By-Laws may be considered, all old and new business shall be discussed, and recommendations may be voted for presentation at the annual meeting.

VI

A—Amendments

1. These By-Laws may be amended by favorable vote of the Business Committee, providing that such changes have been recommended and legality approved by the Executive Committee. Such amendments shall be published in the next regular number of the recognized organ of the Society.

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Gaby, Phil P.
Ludwick, Lt. C. C.
Glendale
Dodd, Lavon C.
Eichelberger, A. M., Jr.
Waterfall, Louis N.
Huntington Park
Agee, F. H.
Hill, Roy A.
Lomita
Urguhart, Clair
Long Beach
Gilmore, R. L.
Taylor, DeWitt E.
Los Angeles
Adams, John A.
Batchelder, Dean E.
Boccalery, M. A.
Born, Milton C.
Clark, R. W.
Cole, J. Gordon
Dresbach, C. H.
English, Walter A.
Erickson, E. L.
Gabriel, V. G.
Hathaway, Jos. G.
Jakosky, Jos. J.
Kempsky, Phillip J.
Leathers, C. H.
Lester, O. C., Jr.
McCloskey, Downs
McGrady, H. D.
Mollere, John C.
Price, W. R., Jr.
Salvatori, Henry
Shade, N. R.
Smith, Warren H.
Statham, Louis
Walling, Dean
Modesto
Ferber, Herbert J.
Heggblom, J. C.
Pezdek, Victor J.
Pacific Palisades
Sweet, Elliot
Pasadena
Benioff, Hugo
Bevier, George M.
Christie, Norman J.
Denning, Wayne H.
Dix, C. H.
Fu, Ch'eng Yi
Garber, Allen J., Jr.
Gerdes, C. H.
Grossling, Bernardo F.
Gutenberg, Beno
Hale, C. Russell
Harding, Maynard W.
Hoover, Herbert, Jr.
Howell, B. F.
Legge, J. A., Jr.
Mace, H. G.
McLemore, Ethel Ward
Mansfield, R. H.
Miller, Nash H.
Moran, R. B., Jr.
Myers, W. H.
Peterson, Raymond A.
Pielemeier, E. A.
Rupnik, John J.
Soske, Joshua L.
Thornburgh, H. R.
Reseda
Adams, Ens. Robt. W.
Rosemead
Wiancko, Floyd Eugene
Sacramento
Cohick, Kenneth S.
San Diego
Long, Col. John V.
San Francisco
Hillis, Donuil
Parkhurst, Geo. L.
Williston, Samuel H.
San Gabriel
Sorge, B. W.
San Marino
Johnson, Curtis H.
South Pasadena
Nomann, Arthur B.
Stick, John C., Jr.
Whittier
Moore, Horace S.

COLORADO

Boulder
Longley, W. Warren
Denver
Aurand, Harry A.
Boos, C. Maynard
Duffner, Ens. Ralph T.
Hathaway, Claude M.

Heiland, C. A.
Manning, Capt. A. B.
Marble, Kenneth R.
Murray, Matthew T.
Pakiser, Louis C.
Rugg, Ens. Allen M.

Glenwood Springs
Ervin, Major Lynn D.

Golden
Coolbaugh, David F.
Levings, W. S.

Greeley
Pratt, John F.

Hugo
Musgrave, Albert W.

Kittredge
Zenor, H. M.

La Junta
Ballard, Jas. A.

Springfield
Ferguson, Joe L.

DISTRICT OF COLUMBIA

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Straley, H. W., III.

Tacoma Park
Lash, Chas. C.

Washington
Beresford, Robt.
Brenner, Morris
Dobrin, Milton B.
Erickson, Anton
Gould, Martin J.
Hawkes, H. E.
Heroy, Wm. B.
Hoffman, Malvin G.
Kaiser, Lt.-Col. Geo. B.
Kendall, Jas. M.
Kimble, Henry R.
McGhee, Lt. (jg.) Geo. C.
Muzzey, David S.
Ritzman, O. F.
Smith, R. Ellis
Urick, R. J.
Van Orstrand, C. E.
Willis, Floyd, Jr.

FLORIDA

Coral Gables
Blanchard, Wm. G.

Milton
Walling, F. Rex

St. Petersburg
Albright, E. G.

Tallahassee
Ferguson, F. T.
Freel, J. F.
McCaleb, M. M.

ILLINOIS

Chicago
Cram, Ira H.

Robinson
Davies, Nathan C.

Roodhouse
Dunavan, W. A.

INDIANA

Lafayette
Serviss, Fred L.

West Baden Springs
Birkenhauer, Henry F., S.J.

KANSAS

Kansas City
Jones, H. H.

Larned
Hurd, Clinton O.

Wichita
Mercier, Vincent J.

LOUISIANA

Baton Rouge
Bloomer, P. A.
Halsey, Raymond E.
Roy, Chalmer J.

Ferriday
Gulmon, G. W.

Franklin
Gallaway, Roy Lee

Hammond
Sklar, Maurice

Harvey
Reichert, H. C.

Houma
Lewis, Karl E.
Ratliff, D. W.

Jena
Porter, Hugh

Kentwood
Curnutt, F. E.

Lake Charles
Bugbee, J. M.

New Orleans
Brown, L. I.
Crider, L. C.
Dobrick, Edward G., Jr.
Frey, M. G.
Gill, Robt. J.
Holmer, Ralph C.
Hoover, J. W.
Howe, Ralph H.
Hudson, Joe B.
McDougall, John E.
Meitzen, J. B.
Nichols, E. Turnley
Northrupp, Jos. W. III.
Partridge, John F.
Smith, Neal J.
Todd, Jas. H.
Treybig, B. H.
Wiley, W. B.

Opelousas
Shafer, Russell E.

Ruston
Kretz, R. L.

Shreveport
Barret, Wm. M.
Buchner, Harry M.
Burroughs, B. B.
Caster, E. L.
Fischer, L. F.
Freeman, L. I.
Goebel, Lawrence A.
Harkness, T. O.
Howard, G. C.
Hurry, Clare N.
Keen, C. D.
Lea, W. T.
Lindsey, E. B.
Rosenkranz, R. R.
Smith, C. B.
Spencer, Leslie C.
Taylor, John E.
Wells, Wm. M.
Wilson, Richard M.

Sulphur
McAlister, C. H.
Moore, James A.
Whiton, Herman F.

MARYLAND

Baltimore
Joesting, Henry R.
Swartz, J. H.

Silver Spring
Lohse, John M.
Melton, Ben S.
Paddison, Louis J.

MASSACHUSETTS

Brighton
Cronin, Eugene J.

Brookline
Maxwell, E.

Cambridge
Beers, R. F.
Bradford, Donald C.
Doss, C. L.
Oliphant, Chas. W.
Tripp, Maurice
Woodward, R. H.

Everett
Haskell, Norman A.

Medford
Morgan, Chas. Gill

South Lincoln
O'Boyle, Chas. C.
Weston
Linehan, Rev. Daniel, S. J.
Woods Hole
Peoples, J. A., Jr.

MINNESOTA

New Ulm
Pollei, Donald W.
Virginia
Kendall, John M.

MISSISSIPPI

Gulfport
Shapard, C. A.
Hattiesburg
Calhoun, F. F.
Jackson
Gaby, Ewin D.
Perry, W. B.
Rozsa, Theo.
Laurel
Jasper, Walter E.
McComb
Martin, Cpl. W. Obier
Natchez
Ferguson, J. G.
Marshall, H. D.
Strange, Booth B.
Strange, O. A.
West Jackson
Harvey, Castle J. C.

MISSOURI

Camp Crowder
Bowsky, Lt.-Col. M. C.
Joplin
Busby, Elton
Seyffert, Willis A.
Latimer, M. W.
Kansas City
Fain, Lt.-Comdr. Edgar A.
Meador, B. M.
Rockport
Polson, Mrs. G. S.
St. Louis
Blum, Victor J., S. J.
Macelwane, Rev. J. B., S.J.
McCormack, Harold R.
Robertson, Miss Florence
Stearn, Noel H.

MONTANA

Billings
Cady, Francis H.
Warren, Kirby J.
Choteau
McGann, R. J.
Miles City
Colvin, C. E.

NEBRASKA

Lincoln
Bates, Lt. Chas C.
Souther, J. B.

NEW JERSEY

Asbury Park
Loring, Ralph C.
Montclair
Winkler, B. O.
Mountain Lakes
Stanton-Ross, John Taylor

NEW MEXICO

Artesia
Whelan, Mark
Clayton
Renden, Hugo R.
Farmington
Forward, Fred
Hobbs
Moore, J. Hiram
Thompson, Grady

NEW YORK

Amawalk
Kelly, Sherwin F.
Garden City
Doolittle, Russell C.
Hempstead
White, Gifford E.
Ithica
Baird, John
Larchmont
Jansen, M., Ir. J. J. H.
New York
Bush, F. A.
Ewing, Maurice
Faul, Henry
Gibbon, H. A.
Hardy, W. W.
Hubbard, Bela
Jensen, Homer
Kaufman, G. F.
Kogbetliantz, Ervand Geo.
Lynch, J. Joseph, S.J.
Milstein, Mark N.
Olson, W. S.
Pekeris, C. L.
Rieber, Frank
Schwennesen, A. T.
Skeels, D. C.
Weichert, R. F., Jr.
Zavoico, Basil B.
Rochester
Thompkins, F. A.
Syracuse
Siegert, A. J. F.
Wellsville
Young, Wilber H., Jr.
West Point
Honnell, Lt.-Col. P. M.

NORTH CAROLINA

Raleigh
Miller, E. L., Jr.

OHIO

Cincinnati
Day, Charles E.
Dayton
Koenig, Palmer E.
Fairfield
Nash, Cleve C.
Middleport
Hersey, Lt. (jg) J. B.

OKLAHOMA

Ardmore
Divelbiss, James
Bartlesville
Bondurant, J. E.
Bradley, R. M.
Brownlow, C. L.
Courtier, Wm. H.
Crenshaw, C. C.
Dietert, Arthur E.
Ericson, Harry B.
Hintze, A. J.
Johnson, E. W.
Kidd, Robt. L.
McNally, P. M.
Miller, Vincent
Owen, H. J.
Piety, R. G.
Chickasha
Stones, J. Eugene
Clinton
Fischer, Leon
Elk City
Breedlove, Miss Ruth
El Reno
Meade, Geo. N.
Enid
Clifton, R. L.
Ft. Sill
Hunkapillar, B. B.
Norman
Schriever, Wm.
Oklahoma City
Feather, V. G.
Jones, Leland W.
Kamitchis, James E.
Maxey, J. R.

McMullin, Major Elbert F.
Rutherford, Homer E.
Trombla, L. B.
Wolff, D. J.

Ponca City

Athy, L. F.
Crawford, John M.
Haber, A. F.
Jordan, C. K.
Kipfer, H. L.
Mount, E. L.
Northcutt, W. C.
Prescott, H. R.
Richards, L. J.
Searcy, Frank
Smith, Franis E.
Swan, Bird G.
Vorheis, Byron
Warren, Paul R.
Whitehead, L. E.

Shawnee

Buck, R. D.
Lukens, John P.
Smith, D. F.

Stilwell

Hawes, Julian K.

Tulsa

Anderson, John F.
Andrews, H. H.
Balbin, Paul D.
Barthelmes, Albert J.
Baum, Robert
Becker, H. C.
Bevan, Thomas J.
Bills, Robert N.
Bishop, F. L.
Borman, F. W.
Born, W. T.
Boucher, F. G.
Bowman, D. C.
Breck, Howard R.
Brown, Henry W.
Bryan, A. B.
Buffum, C. E.
Bullock, Robert L.
Burg, Kenneth E.
Burton, R. H.
Campbell, H. H.
Carter, R. W.
Clark, R. C.
Coffin, R Clare
Connell, Joe E.
Cooley E. H.
Cooper, Jack R.
Cornette, J. R.
Cornish, Lou G.
Doll, W. R.
Duller, Charles E.
Egan, Danie. G.
Eisler, Joseph D.
Emanuel, Vincent
Erdahl, Wm. M.
Evans, Julian F.
Faust, L. Y.
Fearon, R. E.
Ferguson, John L.
Ferris, Craig
Finn, Robert S.
Fitch, A. A.
Friendly, Jack L.
Frost, Noel
Fruehling, S. W.
Garner, J. P.
Gemmer, R. W.
Gilliam, J. T.
Gilmour, Andrew
Giltinan, G. M.
Green, W. G.
Grimm, G. A.
Handley, E. J.
Harbach, Robert G.
Harlton, Bruce H.
Hartline, Ralph E.
Hawkins, J. E.
Hays, Clyde L.
Hoffman, John C.
Hollis, Jack L.
House, A. Maxwell
Innes, Arland I.
Jeffers, Paul H.
Johnson, J. R.
Jones, Huston R., Jr.
Jones, John Paul
Jones, V. L.
Kendall, G. D.
Kendall, W. B.
Kezeler, J. L.
Kittredge, F. R.
Kriegel, Monroe W.
Kundert, Karl H.
Lambert, G. D.
Lambkin, Woodrow W.
Lawrence, K. M.
Laws, J. O.
Leady, F. B.
Leverich, Priestley
Manhart, T. A.
Martens, Willis P.
Martin, Dick
Mayes, Tom D.
McClure, C. E.
McCollum, Elton V.
McCready, H. J.
McNatt, E. M.
Mehringer, A. P.
Moody, N. K., Jr.
Moore, Homer C.
Mossman, R. W.
Naremore, D. W.
Nash, John M.
Neufeld, J.
Notley, W. E.
Novelly, Walter O.
Officer, Helen V.
Owen, John E.
Page, C. Newton
Palmer, John E.
Peery, W. R.
Rankin, C. T.
Reed, Geo. W.
Reid, A. C.
Richardson, J. W.
Rickel, Wesley K.
Ricker, Norman
Riess, Malcolm
Roark, James J.
Robertson, K. A.
Romberg, M.
Ross, Charles M.
Rutledge, Richard B.
Schempf, Edward G.
Scherbatskoy, S. A.
Scott, C. B.
Seaman, L. O.
Sharpe, Joseph A.
Sheffet, David
Sibley, W. B.
Silverman, Daniel
Smith, Frank B.
Southgate, Tom F.
Sparks, Neil R.
Stotler, Thomas C.
Strachan, Clyde G.
Swearingen, A. C.
Sype, William R.
Taylor, Albert
Taylor, Garvin L.
Tefft, Gerald H.
Thomas, T. J.
Thralls, H. M.
Tucker, R. H.
Van Croy, Stefan
Van der Linden, E. J. P.
Van Valkenburgh, J. C.
Vernon, Jess
Wagoner, G. E.
Waldrep, W. Day
Walton, James I.
Wantland, Dart
Watson, Robert J.
Weatherby, B. B.
Weingartner, R. A.
Westby, G. H.
Widess, M. B.
Wilcox, Stanley W.
Williams, P. S.
Wilson, James N.
Winn, Clayton M.
Winnek, J. R.
Woodburn, James E.
Woolson, John R.
Zimerman, Sam

PENNSYLVANIA

Bethlehem
Agocs, W. B.
Erie
Weunschel, Paul C.
Lemoyne
Jones, J. Byron
Norwood
Bazzoni, Charles B.
Pittsburgh
Affleck, Jamer
Allon, Michael
Backman, John E.
Bailey, Lothrop H.
Barbour, P. C
Bender, Fred A.
Butler, Mark D.
Cereveny, Philip F.
Cook, D. E.
Copeland, R. J.
DeGood, R. G.
DeWoody, D. A.
Diveley, Paul R.
Dombart, William F.
Eckhardt, E. A.
Elkins, Thomas A.
Fink, Paul O.
Gardner, Louis W.
Gealy, Wendell B.
Gemmell, Howard F.
Gunn, J. E.
Hammer, Sigmund I.
Hastings, W. K.
Herron, Robert C.
Hoylman, H. Wayne
Jones, R. W.
Kerbow, R. B.
Kilborn, J. M.
Lamb, Wm. C.
McCracken, Guy I.
Muffly, Gary
Muskat, Morris
Nettleton, L. L.
O'Donnell, Thomas J.
Palmer, E. M.
Palmer, Loyal D.
Peters, Leo J.
Reiser, Robert G.
Robinson, W. Bernard
Ross, R. B.
Scott, D. L.
Smith, Douglas H.
Staples, Guy W.
Texter, John W.
Tomlinson, John B.
Watson, George R.
Wert, Carl M.
Westrick, E. W.
Wickerham, M. D.
Wyckoff, Ralph D.
Ridley Park
Johnson, F. L.
State College
Pirson, Sylvain J.

TENNESSEE

Oakridge
Garrett, Geo. A.
Perret, Wm. R.

TEXAS

Athens
Smitherman, Lynn A.
Austin
Brown, Leon D., Jr.
Hughes, Darrell S.
Konz, Leo W.
Mims, R. Lewis
Romberg, Frederick E.
Beaumont
Carson, Roe W.
Conklin, Glenn M.
Ellis, L. G.
Hollingsworth, W. E.
Millington, John W.
Nahas, J. N.
Rose, H. W.
Siegel, Frank
Smiley, W. G., Jr.
Winterhalter, A.
Bellaire
Beeman, Keith R.
Buckner, Guy O.
Cowles, Laurence G.
Eby, A. N.
Wolf, Alexander
Big Lake
Harkey, W. J.
Big Spring
Barnes, Chester F.
Birthright
Hargis, A. V.
Coleman
Cheney, Monroe G.
Cooper
Noble, Francis H.
Corpus Christi
Howerton, Bert P.
McGuickin, Glenn M.
Crane
McDaniel, C. M.
Peachee, D. A.
Crockett
Itten, Howard
Dallas
Adams, Hal R.
Agnich, Fred J.
Alcock, E. D.
Arnett, R. D.
Arnold, Kingsland
Augustat, Geo.
Autrey, D. W.
Ayres, J. Otis
Baird, Walter D.
Batson, James D.
Bonebrake, Walter C.
Bradley, H. W.
Brinnon, W. B.
Brown, H. Hallock
Browning, K. A.
Campbell, E. L.
Cathey, John A.
Chang, Tun Yin
Clewell, Dayton H.
Cobb, Howard L.
Collingwood, Douglas M.
Cortes, Henry C.
Dahm, C. G.
DeGolyer, C. L.
Dobyns, D. R.
Donnally, Chester J.
Douglas, Norvel
Dugan, Albert F.
Elms, R. G.
Everitt, James
Farrow, B. D.
Fetzer, E. L.
Fisk, Frank K.
Gaither, Jerrel
Garrett, M. M.
Gary, J. W.
Gillin, John A.
Granberry, H. E.
Gray, William R.
Green, Cecil H.
Gsell, R. N.
Haggerty, Patrick E.
Hamil, A. B.
Hamm, W. Dow
Harris, B. A.
Henderson, J. B. H.
Henderson, Ross
Hieatt, Herbert F.
Hightower, C. H.
Hilger, Mrs. C. L., Jr.
Hogg, W. B.
Horn, J. W.
Houghton, H. M.
Hurt, Worth B.
Jackson, Lt.-Col. Robert W.
Jennings, Bruce M., Jr.
Jones, M. P.
Jonsson, J. E.
Jubran, Joseph
Karcher, J. C.
Kelsey, Martin C.
Kennedy, Edward P.
Kennedy, Frank H., Jr.
Kohler, G. J.
Livingston, E. C.

Lomax, C. J.
MacNaughton, L. W.
McBurney, Charles G.
McCarver, Holland C.
McDermott, Eugene
McKay, A. E.
Menefee, James C.
Minton, J. P.
Mitchell, W. R.
Moon, Jake
Moore, Charles M., Jr.
Moore, F. A.
Myers, John R.
Nash, Paul E.
Newton, W. W.
Nugent, Roderick M.
Oden, A. J.
Owings, B. F.
Pasley, L. C.
Payne, J. E.
Pernell, J. H.
Perryman, J. D.
Peters, Jack W.
Pittman, C. V. A.
Pratt, R. B.
Ransom, J. H.
Ransone, W. R.
Raper, W. B.
Reagor, Edward C.
Reeves, J. R.
Ranner, Darwin S.
Robinson, George W.
Rollins, J. Frank
Russell, Dallas L.
Schley, Woodruff H.
Seifert, Wesley H.
Seiler, George E.
Shepherd, Capt. Cuth K.
Shugart, T. R.
Smith, Randolph
Stanton, Austin N.
Steel, D. M.
Storm, Alfred E.
Stulken, E. J.
Sturdevant, John M.
Tabor, E. M.
Terry, R. D.
Thompson, Atlas H.
Thompson, R. P.
Tottenham, W. M.
Tucker, Robert L.
Valkus, James W.
Van Cleave, R. F.
Waller, J. A., Jr.
Walsh, T. N.
Waters, Kenneth H.
White, Rex H.
Williams, Charles C.
Williams, Floyd J.
Wilson, E. E.
Woods, J. P.
Woolley, William C.

Danbury

Garrett, William M.

Ft. Worth

Dana, R. H.
Davis, Rollin E.
Dyk, Karl
England, C. M.
Harris, Sidon
Hollingsworth, W. Wise
Hunzicker, A. A.
Johnson, James F.
Konkel, T. L.
Lang, Ralph H.
Ledyard, Paul H.
Lovejoy, J. B.
Morris, James L.
Normand, S. R.
Peabody, Gwendolyn
Sanders, C. W.
Sandidge, Irl, Jr.
Schouten, F. H.
Suggs, M. L.
Thomsen, Erik
Van Steenbergh, S. K.
Wilson, John H.

Frijole

Pratt, Wallace E.

Garland

Conover, Geo. E.

Grand Prairie

Stommel, H. E.

Grapevine

Deacon, L. E.

Hamilton

Stiles, Elisabeth

Houston

Aderman, C. V.
Adler, Joseph L.
Aiken, Charles B.
Anderson, O. W.
Arthur, M. A.
Bader, Glenn E.
Banta, H. E.
Banta, N. H.
Barnette, L. Atmar M.
Beeth, Donald
Bennett, Roy F.
Berg, G. A.
Berndes, A. E., Jr.
Bertram, A. C.
Bible, John L.
Bivens, Bobby
Black, J. P.
Blau, L. W.
Blight, Richard E.
Bolinger, John W.
Boyd, Lewis H.
Briard, Vernon E.
Brooks, James A.
Brown, Andrew
Brown, Donald R.
Brown, Hart
Broussard, C. H.
Broussard, D. F.
Bruyere, R. M.
Bryan, Carl L.
Bunsen, A. W.
Burnett, A. C.
Butler, W. W.
Campbell, David B., Jr.
Campbell, F. F.
Carlton, Dave P.
Carr, G. W.
Cash, Harvey, Jr.
Charrin, Paul J. D.
Child, V. E.
Clark, Geo. B.
Clark, W. C.
Clayton, Neal
Cole, R. C.
Conley, H. R.
Crary, Donald
Crowell, J. H.
Culbertson, J. A.
Culp, H. A.
Davis, Donald M.
Deming, J. H.
Deussen, Alexander
Doll, H. G.
Dunlap, A. D.
Duty, Robert S., Jr.
Eberts, A. G.
Eby, J. Brian
Epperson, R. S.
Evjen, H. M.
Falkenhagen, H. M.
Ferguson, J. B.
Finnigan, Thomas L.
Flude, J. W.
Fohs, F. Julius
Frosch, Alex
Frowe, Eugene
Futral, John E.
Gardner, Derry H.
George, Fred W.
Gibson, M. O.
Giezendanner, S. S.
Gilmore, John A.
Goldstone, Frank
Goss, Henry V.
Grange, Donald C.
Griffin, I. M., Jr.
Guseman, L. F.
Guyod, H.
Hafner, W.
Hall, T. O.
Hamilton, W. Brooke
Hamm, J. G.
Hammial, L. L.
Happel, Henry H.

Harding, R. N.
Harkins, Curtis P.
Harkins, T. I.
Harrington, Geo. H.
Harris, John
Haynes, C. J.
Henderson, M. R.
Henquet, R.
Herzenberg, A. J.
Hibbler, Alfred J.
Hibbler, M. E.
Hillyer, Ray H.
Hinson, Cecil C.
Hoard, J. O.
Holekamp, O. G.
Horton, C. W.
Horvitz, Leo
Houston, Charles E.
Hovey, Ivan C.
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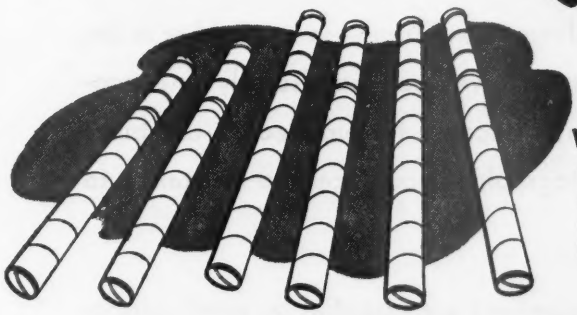

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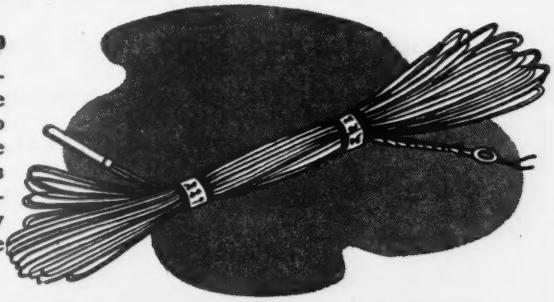

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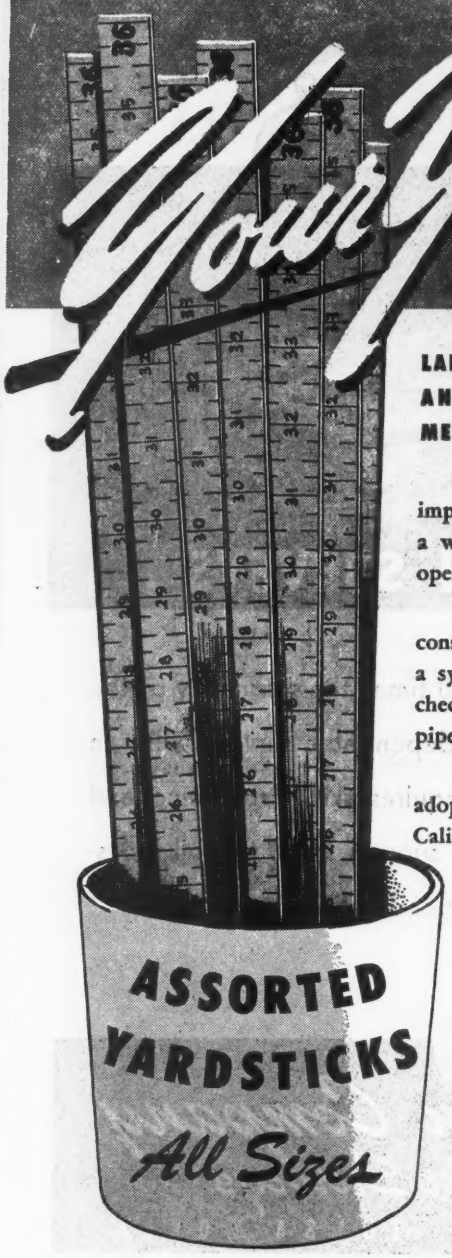

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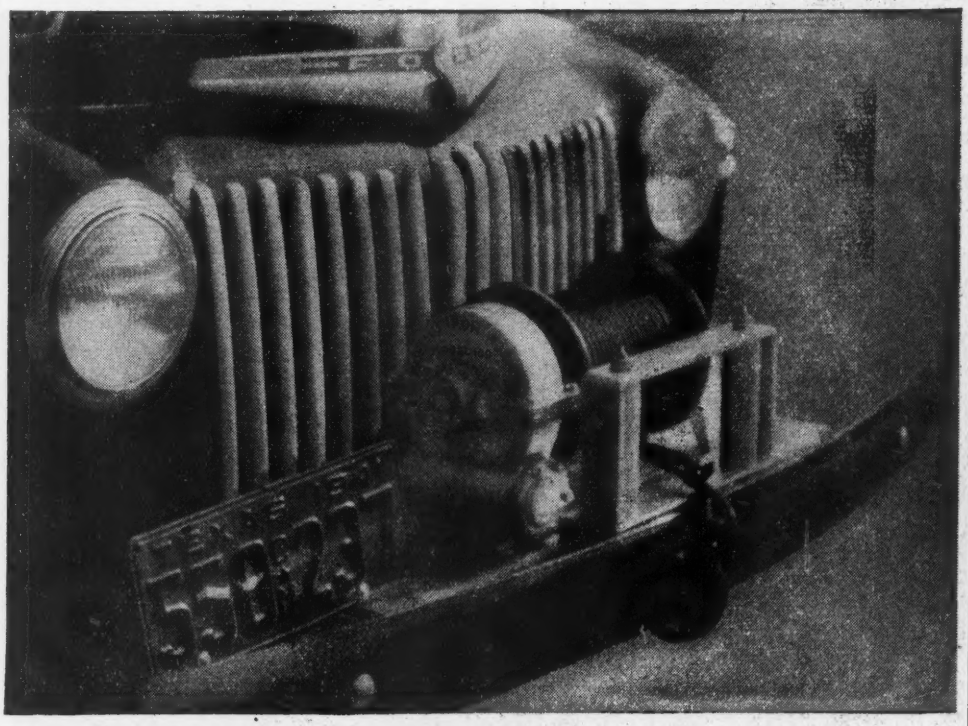

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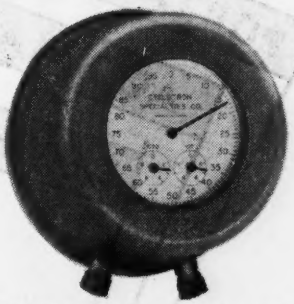

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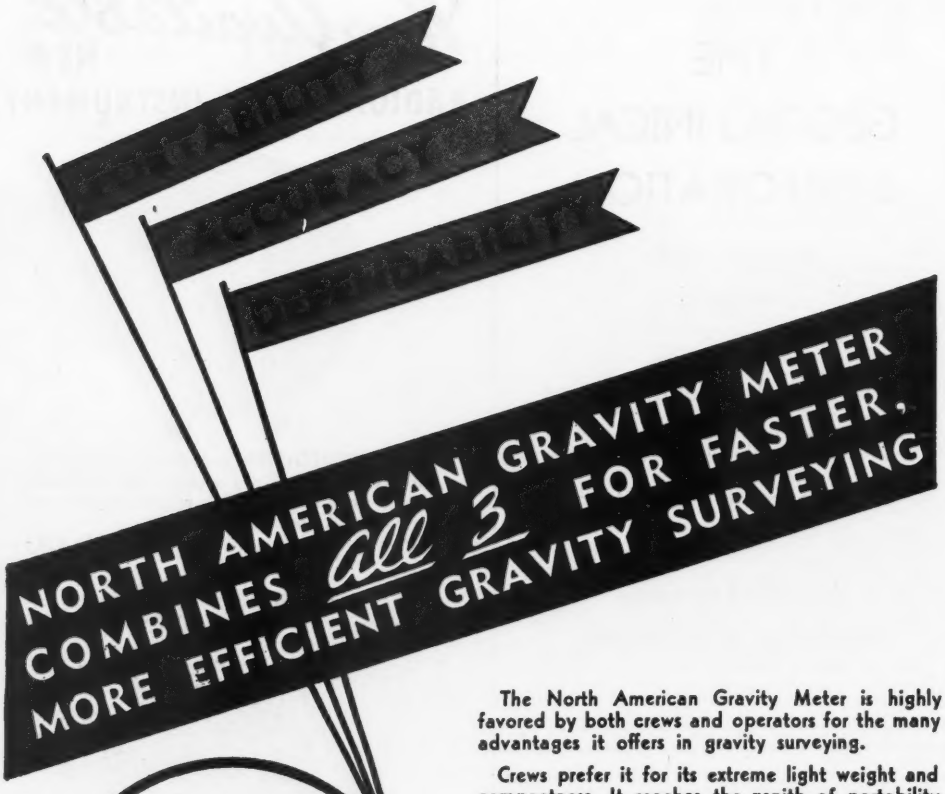

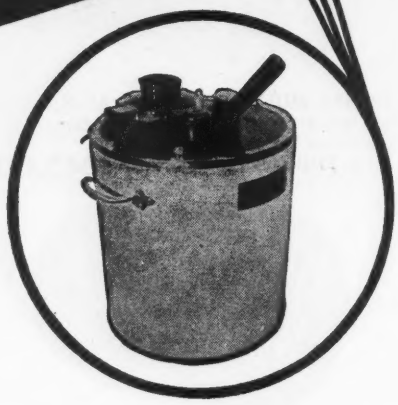

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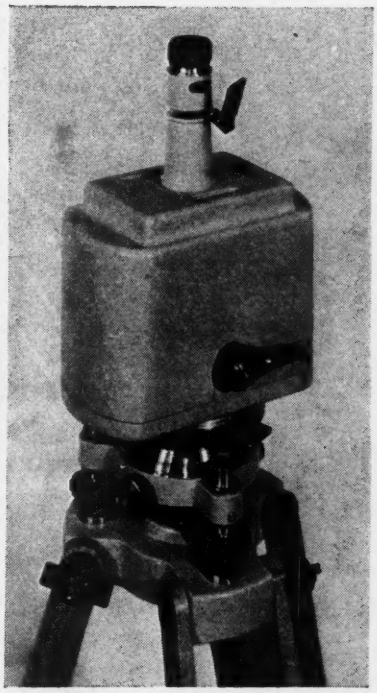

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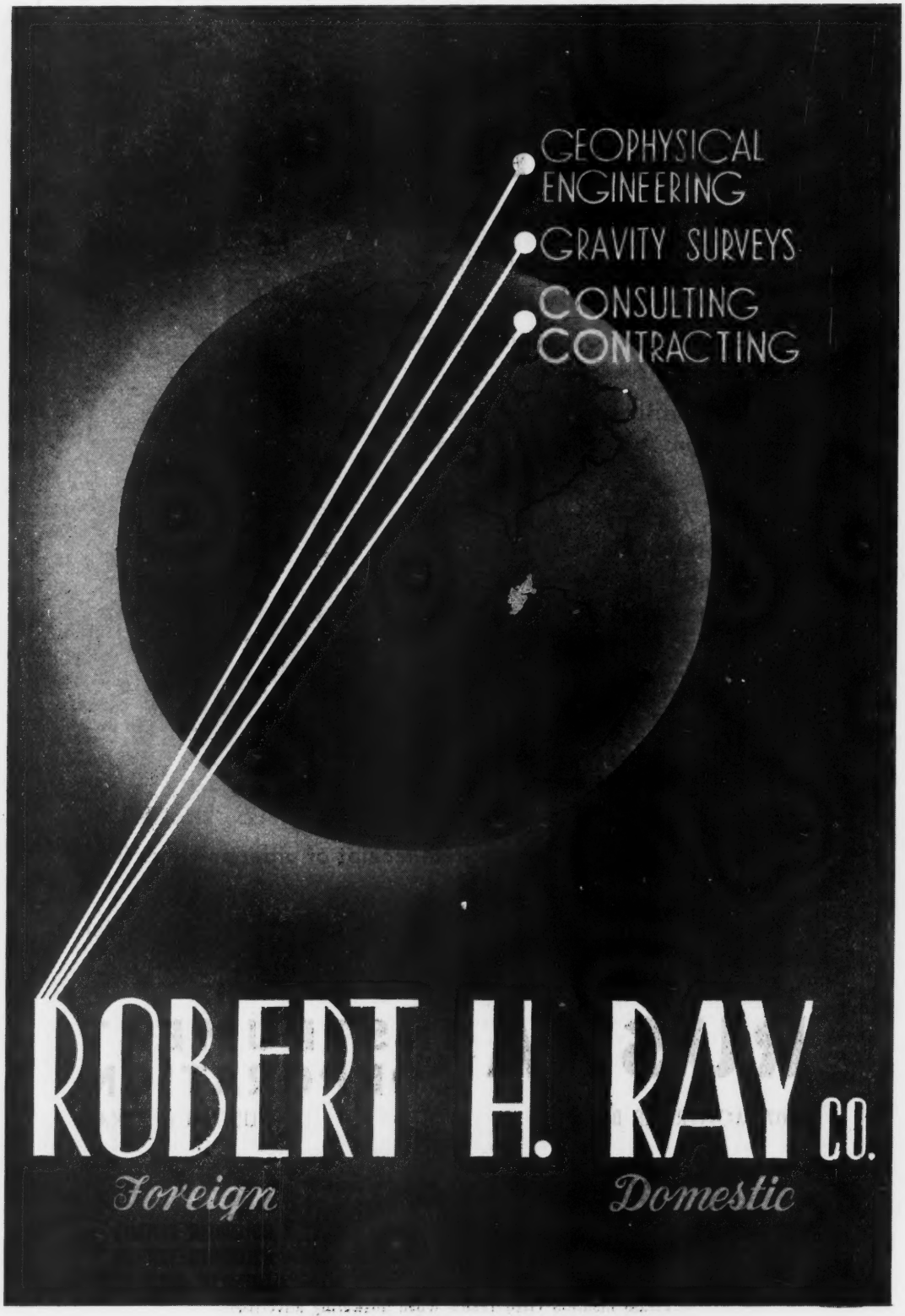
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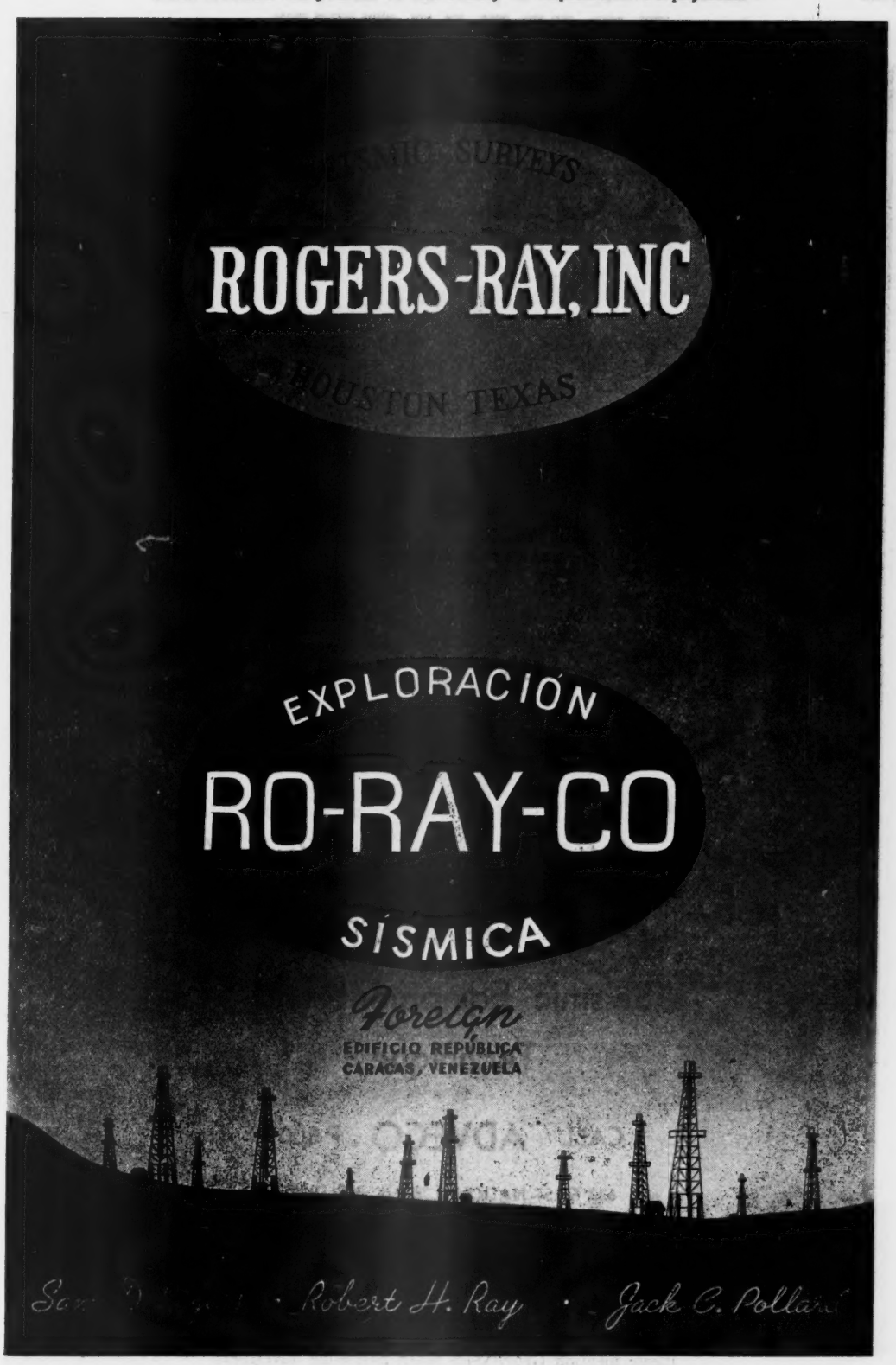
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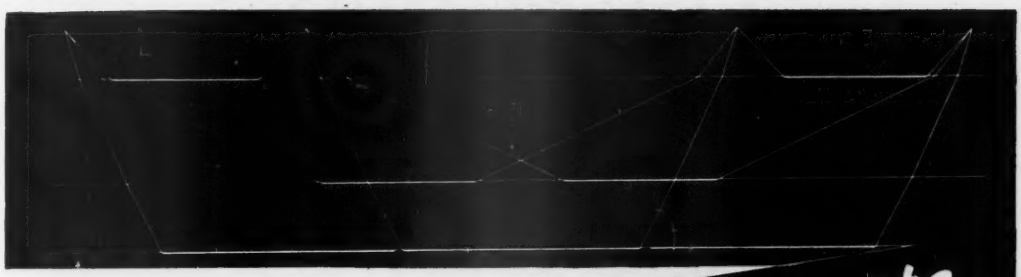

Schematic diagram of one method of application.

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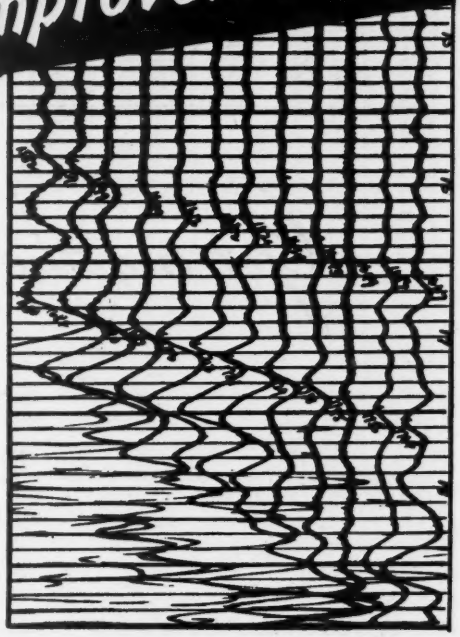

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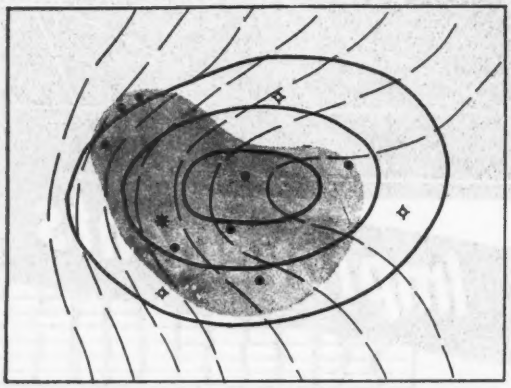

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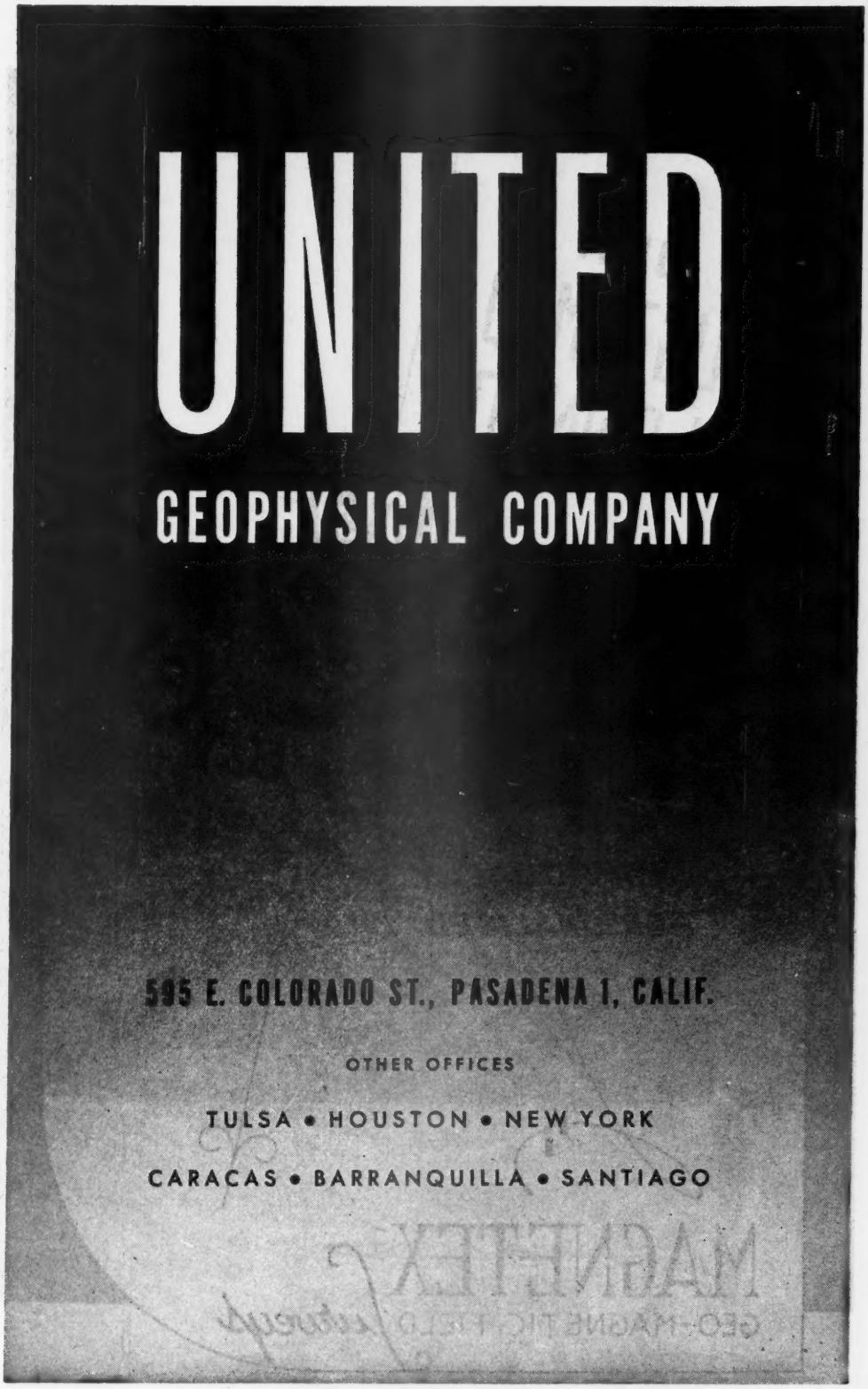
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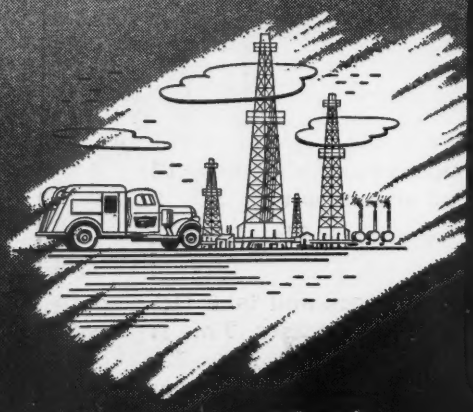

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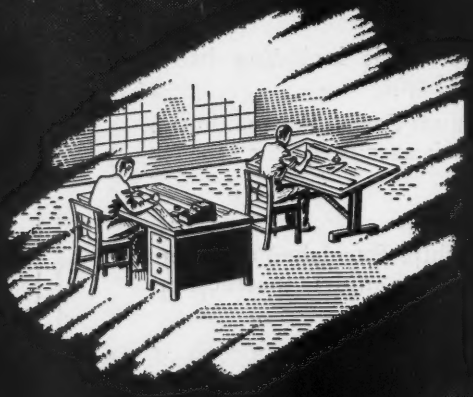

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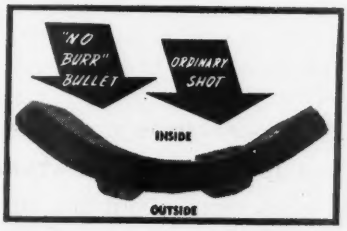

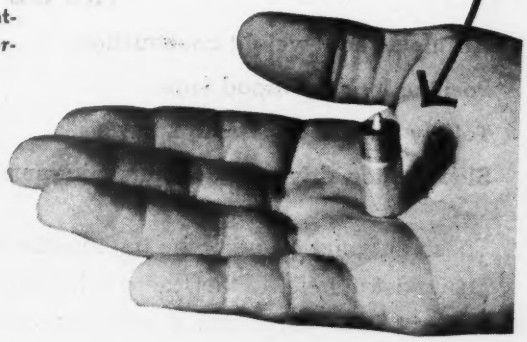

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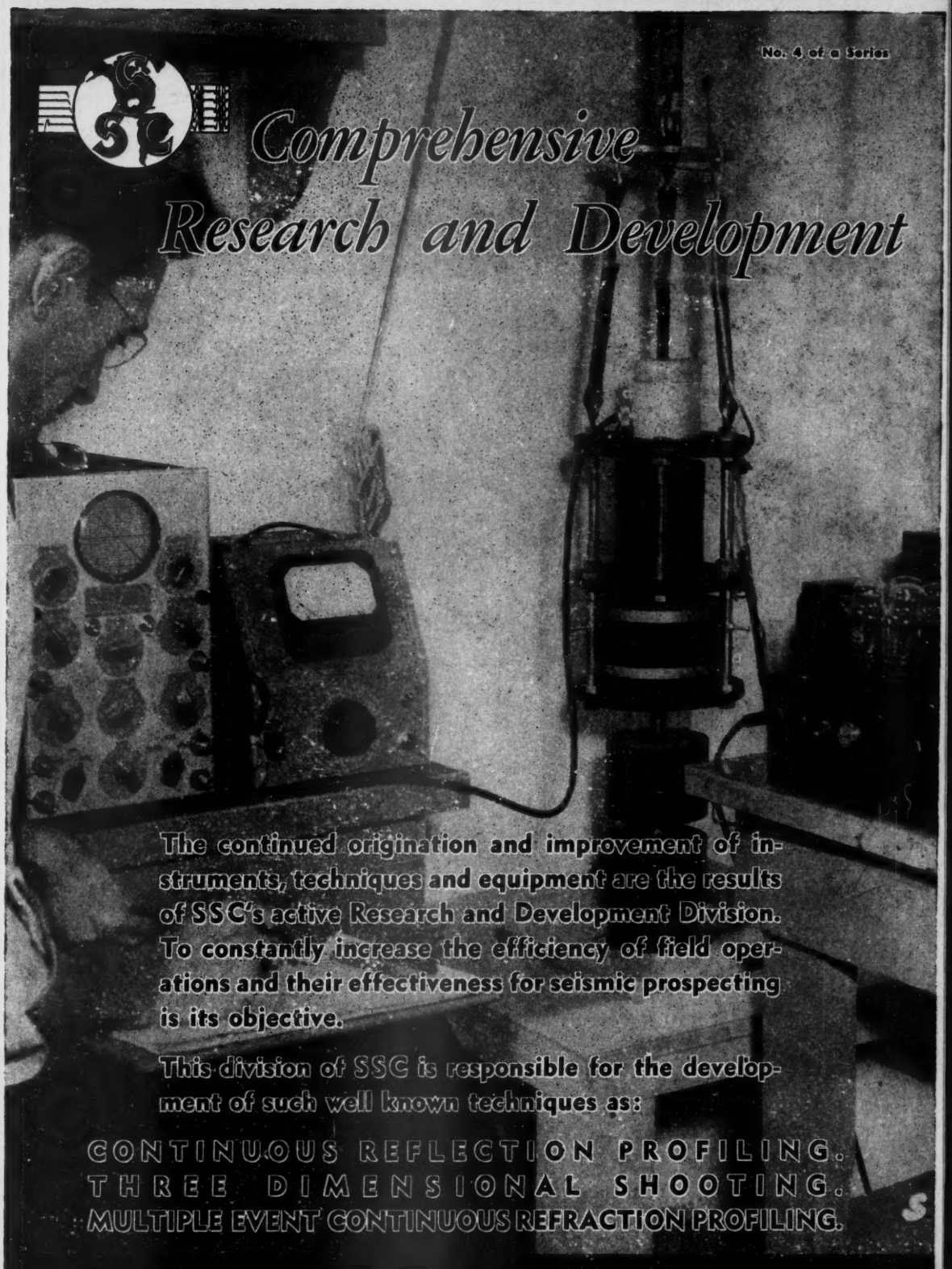

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